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ABSTRACT

The annotated bibliography is intended to aid geologists whose primary background is not in geochemistry. The references thus range from chemistry texts to papers on complex geochemical applications. The emphasis has been on those books and papers concerned with the application of chemical concepts to geology. Citations are arranged topically to provide a quick guide to the literature on the topics. Within each section the citations are arranged alphabetically. Where a paper selected for inclusion fits well into two or more sections, an arbitrary assignment has been made to one in order to avoid unnecessary duplication. An estimate of the mathematics and chemical background necessary for comprehension of each citation is noted. Topic sections include: (1) crystal chemistry; (2) physical chemistry; (3) kinetics; (4) applications of chemical concepts to high-temperature geologic systems; (5) applications of chemical concepts of low temperature geologic systems; (6) application of chemical concepts to natural organic systems; and (7) application of chemical concepts to isotope geology. (Author/JN)

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Chemical Geology: An Annotated Bibliography

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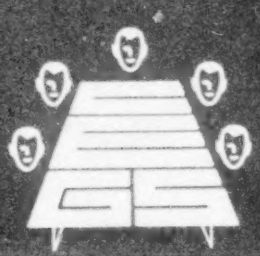

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11. Paleoecology: Fossils and Their Environments, by Leo F. Laporte. 1969, v. 17, no. 3, p. 75-80.
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*13. Computer-Oriented Laboratory Exercises for Geology and Oceanography, by William T. Fox. 1969, v. 17, no. 4, p. 125-134.
14. Guide to Geological Literature, by Harriet W. Smith. 1970, v. 18, no. 1, p. 13-25.
*15. Ash-Flow Deposits—Their Character, Origin, and Significance, by Donald W. Peterson. 1970, v. 18, no. 2, p. 66-76.
*16. Deltas—A Resumé, by James P. Morgan. 1970, v. 18, no. 3, p. 107-117.
*17. Shoreline Processes, by John H. Hoyt. 1972, v. 20, no. 1, p. 16-22.
*18. The Estuarine Environment, Part 1, by J. R. Schubel and D. W. Pritchard. 1972, v. 20, no. 2, p. 60-68.
*19. Dolomitization and Uniformitarianism, by Donald H. Zenger. 1972, v. 20, no. 3, p. 107-124.
*20. The Estuarine Environment, Part 2, by J. R. Schubel and D. W. Pritchard. 1972, v. 20, no. 4, p. 179-188.

*out of print

Continued on back cover

CEGS PROGRAMS PUBLICATION
NUMBER 11

Chemical Geology: An Annotated Bibliography

By

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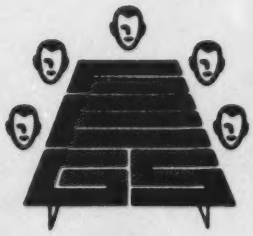

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FOREWORD

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Chairman

Chemical Geology: An Annotated Bibliography is one part of the Professional Development Panel's three-part Geochemistry Sequence. Coordinated with this bibliography is the Special Issue of the *Journal of Geological Education*, Vol. XX, No. 5 (CEGS Programs Publication Number 10), composed of papers presented at the CEGS-sponsored Symposium on Low-Temperature Geochemistry held at the annual meetings of the Geological Society of America and Associated Societies on 11 November 1970 in Milwaukee.

The association of this bibliography with the symposium and related symposium volume explains somewhat the skewed distribution of citations toward solution geochemistry and away from element distribution and the contribution of isotope geochemistry to geochronology.

O.T. Hayward, when he was Director, provided the first impetus in CEGS toward a geochemistry bibliography and began collecting critical references. David Delo and Peter Fenner later reactivated the work, and Fenner, with help from the Professional Development Panel, succeeded in arranging the full sequence.

On behalf of CEGS and the profession I want to thank Gale Billings for this stimulating and educational contribution to chemical geology. He is to be especially commended for his patience and fortitude. CEGS accepts total responsibility for the delay in publication.

George R. Rapp, Jr.
Chairman, CEGS

PREFACE

This annotated bibliography is intended to aid geologists whose primary background is not in geochemistry. The references thus range from chemistry texts to papers on complex geochemical applications. The emphasis has been on those books and papers that are concerned with the application of chemical concepts to geology. This has led to a number of arbitrary, but carefully considered, omissions, such as the wealth of geochemical knowledge on the distribution of elements within the earth. The obvious reason for selection is the size of an all-inclusive bibliography.

The references include a brief annotation, and an estimate of the mathematical and chemical background necessary for comprehension. When an author's abstract appeared to be succinctly written a large part of it was often included in the annotation without specific acknowledgment. References are generally cited only if they are readily accessible.

The manuscript was reviewed by Donald R. Baker, Robert G. Reeves, and G.J. Schrayer. This was not an easy task and I gratefully acknowledge their help. Bevan Devine, a former student of mine, contributed greatly. The Department of Geology, Louisiana State University, and Department of Geoscience, New Mexico Institute of Mining and Technology contributed valuable secretarial help.

Finally, it is a pleasure to acknowledge those geochemists who took the time to contribute to this bibliography: D.L. Biggs; B.J. Burley; R.G. Corbett; W.E. Dean, Jr.; P. Deines; G. Faure; G.G. Goles; R.L. Gresens; J. Houp; P.M. Hurley; F.E. Ingerson; W.F. Libby; M.E. Lipschutz; E.J. Manter; C.B. Moore; G.W. Putnam; D.D. Runnells; C.J. Schneer; F.R. Siegel; T. Takahashi; K.K. Turekian; H.V. Warren; and D.H. Watkinson.

The errors remaining are mine.

Gale K. Billings

INTRODUCTION

The annotated citations in this bibliography are arranged topically to provide a quick guide to the important literature on these topics in chemical geology. Within each section the citations are arranged alphabetically.

Where a paper selected for inclusion fits well in two or more sections an arbitrary assignment has been made to one in order to avoid unnecessary duplication.

This bibliography was compiled as part of the Council on Education in the Geological Sciences Geochemistry Sequence which focused on low-temperature and solution geochemistry. This focus as well as time and space restrictions have dictated the necessary bias in selections.

CRYSTAL CHEMISTRY

Ahrens, L.H. 1952. The use of ionization potentials. Part 1. Ionic radii of the elements. *Geochimica et Cosmochimica Acta*, 2 (3): 155-169.

This discussion has three main objectives: first, to show regularities between ionic radius, ionization potential, and charge, and by so doing to show that for ions in normal isoelectronic sequences, Pauling-type radii are to be recommended over those based entirely on interionic distance measurements; second, to use the ionization potential to determine some unknown radii; and third, to review and revise all published radii of ions other than those in normal isoelectronic sequences. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry.

Ahrens, L.H. 1953. The use of ionization potentials. Part 2. Anion affinity and geochemistry. *Geochimica et Cosmochimica Acta*, 3 (1): 1-29.

The nature of bonds and their mechanism of formation are briefly discussed. It is recommended that the so-called ionic approach be used for interpreting properties of metal-nonmetal compounds no matter whether the bonds are dominantly covalent or dominantly ionic. Anion affinity is defined and ionization potential used as a relative measure of it. Topics discussed include: the separation of elements into sulfide and silicate phases; geochemical coherence; behavior of elements in fractionated silicate minerals; melting points of olivine and of Ge and Ga substituted feldspars; anion affinity and structure; and the ability of elements to form complexes. Attempts at interpretation are made on the bases of valence, size, and anion affinity of cations and the polarizability of the anions. Suitable for graduates and advanced undergraduates. Background necessary: college chemistry and mineralogy.

Ahrens, L.H. 1964. The significance of the chemical bond for controlling the geochemical distribution of the elements - Part I. *In* L.H. Ahrens, Frank Press, and S.K. Runcorn (editors). *Physics and chemistry of the earth*, v. 5. The Macmillan Company, New York: 1-54.

A great variety of bond types are encountered in the minerals, rocks, soils, and waters of the earth. Several major topics on the geochemical significance of the nature of the chemical bond in all these materials, and in a variety of geochemical situations, are considered in this two-part review. The topics covered in Part I are: (1) chemical inertness and siderophile tendency; (2) chalcophile-lithophile tendencies; and (3) the significance of varying degrees of covalency on element association in silicates. Suitable for graduates and advanced undergraduates. Background necessary: introductory college chemistry.

Allen, C.W. 1955. *Astrophysical quantities* (Second Edition). The Athlone Press, London [University of London]: 263 p.

This book contains excellent reliable tables of important astronomical and physical data in a very handy form.

Clark, S.P., Jr. (editor). 1966. *Handbook of physical constants.* Geological Society of America, New York, Memoir 97: 587 p.

This is a fine, authoritative compilation of data on rock composition, elementary abundances, isotopic abundances, crystallography, radioactive decay constants, and other important matters.

Companion, A.L. 1964. *Chemical bonding.* McGraw-Hill Book Company, New York: 155 p.

This book is a clearly written paperback introducing the subject of chemical bonding; it could easily be used as a reference in mineralogy or geochemistry. The author considers quantum theory; the Bohr atom theory; wave mechanics; covalent, ionic, metallic, and van der Waals bonding; and crystal-field theory.

Condon, E.U., and Hugh Odishaw. 1967. *Handbook of physics* (Second Edition). McGraw-Hill Book Company, New York: 1313 p.

Curtis, C.D. 1964. Applications of the crystal-field theory to the inclusion of trace transition elements in minerals during magmatic differentiation. *Geochimica et Cosmochimica Acta*, 28 (3): 389-403.

"The modification, due to Ringwood, of Goldschmidt's rules dealing with the distribution of trace elements in minerals is difficult to apply to the transition elements." A new approach, that of crystal-field theory, predicts semiquantitatively the relative order in which all the transition elements will be concentrated during magmatic differentiation. Data from the Skaergaard Intrusion support the application. Suitable for graduates and advanced undergraduates. Background necessary: physical-atomic chemistry.

Donnay, J.D.H., and David Harker. 1937. A new law of crystal morphology extending the law of Bravais. *American Mineralogist*, 22 (5): 446-467.

This famous paper extends the Bravais rule of the relationship between the shape and lattices of crystals. The authors show that the order of morphological importance of the faces of a crystal is related to the areal density of space group equipoints. Background necessary: elementary mineralogy.

Evans, R.C. 1964. *An introduction to crystal chemistry.* Cambridge University Press, London: 410 p.

This book deals with the crystal chemistry of the various classes of minerals. With its clear presentation, it is recommended as a graduate and undergraduate text in courses concerning crystal structures of the various mineral types. Background necessary: basic college chemistry and physics.

Fyfe, W.S. 1964. *Geochemistry of solids. An introduction.* McGraw-Hill Book Company, New York: 199 p.

This book deals with the solid state crystal chemistry of the various bond types occurring in minerals. It is an undergraduate or graduate-level text, and is clear and easily readable. Background necessary: basic college chemistry and physics along with possibly 1 or 2 inorganic chemistry courses.

Goldsmith, J.R. 1953. A "simplexity principle" and its relation to "ease" of crystallization. *Journal of Geology*, 61 (5): 439-451.

"Crystallization is viewed as a kinetic process, the relative 'ease' of which is influenced by details of the structures involved. The word 'simplexity' is used as a measure of structural complexity. In general, high 'simplexity' is synonymous with disorder, or structural simplicity, or high entropy. Nucleation and growth of phases with high simplexity are favored, in many cases, over more stable compounds of lower 'simplexity.' The aluminosilicate minerals are examined from this point of view. The effects of pressure and of hydroxyl bonding on the crystallization of aluminosilicates are discussed. The crystallization of dolomite in nature is also considered." Suitable for graduates and advanced undergraduates. Background necessary: basic chemistry and mineralogy.

Hauth, W.E., Jr. 1951. Crystal chemistry in ceramics. *Bulletin of the American Ceramic Society*, January through June, 1951. (in 8 parts).

This publication presents a discussion of fundamental crystallographic principles as applied to the structure of silicate minerals. Subtitles in the series include: introduction to crystal chemistry; coordination theory and crystal bonds; Pauling's rules and basic silicate structures; the ortho, pyro, and meta silicates and amphiboles; sheet structure minerals and the feldspars; the clays and micas; poly-

morphism; and the crystal chemistry of glass. Suitable for intermediate undergraduate courses. Good illustrations. Background necessary: basic chemistry.

Holden, Alan, and Phylis Singer. 1960. *Crystals and crystal growing.* Anchor Books, Doubleday and Company, Inc., Garden City, New York: 320 p.

A beginning college-level book on the physics and chemistry of crystals with the dominant theme of methods for growing single crystals. It is very readable and well illustrated.

Keller, W.D. 1969. *Chemistry in introductory geology.* Lucas Brothers Publishers, Columbia, Missouri: 108 p.

This book offers a simplified but nevertheless sound approach to the concepts of chemistry used most commonly in introductory courses. Concepts are illustrated with practical geologic examples. Background necessary: no previous course in chemistry.

Landé, Alfred. 1949. The physical significance of the reciprocal lattice of crystals. *American Scientist*, 37 (3): 414-416.

In this three-page examination of the basic concept of crystal structure, Landé demonstrates that the reciprocal lattice is neither more nor less real than the direct structure. This short paper is desirable for crystal chemistry courses. Background necessary: any course introducing the reciprocal lattice.

McConnell, Duncan. 1967. Crystal chemical calculations. *Geochimica et Cosmochimica Acta*, 31 (9): 1479-1487.

In this article, methods are indicated for calculating: (1) the structure formula for complex minerals; (2) the number of oxygen atoms in the unit cell; (3) the unit-cell dimension of an isometric isotype in a series where the dimensions of several other compositions are known; and (4) the unit-cell volume of an isotype of a non-isometric substance from the volume of a single known structure. Any physical characteristic that will lead to a calculation of the density can be used as a basis for calculating other non-vectorial properties, such as the refractive index of an isotropic substance or the mean refractive index for an anisotropic one. The interrelations among chemical and physical properties are discussed briefly. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry and basic crystal chemistry.

Nockolds, S.R. 1966. The behaviour of some elements during fractional crystallization of magma. *Geochimica et Cosmochimica Acta*, 30 (3): 267-278.

An attempt is made to estimate bonding energies for metal-oxygen bonds, and to use the results to account for the behavior of elements during fractional crystallization of magma. Suitable for graduates and advanced undergraduates. Background necessary: physical chemistry.

Pauling, L.C. 1967. *The nature of the chemical bond.* Cornell University Press, Ithaca, New York: 267 p.

This short paperback serves as an excellent reference to structural chemistry; it would be useful as a supplementary text in mineralogy and geochemistry. Background necessary: basic college chemistry.

Ramberg, Hans. 1952. Chemical bonds and distribution of cations in silicates. *Journal of Geology*, 60 (4): 331-355.

"It is shown on theoretical grounds that the electronegativity of oxygen in silicates depends upon the Si-O structure as well as upon the Al/Si ratio in $(Si/Al)O_4$ tetrahedra." How the different metallic cations distribute themselves among the different types of silicates, depending on the variable electronegativity of oxygen in the structures and on the position of the metals in the electronegativity scale of elements, is discussed. The rock-forming minerals are in good agreement with the theory. Suitable for graduates and advanced and intermediate undergraduates. Background necessary: basic college chemistry and mineralogy.

Roy, Rustum. 1963. Crystal chemistry in research on ionic solids. *In* Cyrus Klingsberg (editor). *Physics and chemistry of ceramics* [Proceedings of a symposium at Pennsylvania State University]. Gordon and Breach Science Publishers, Inc., New York: 45-76.

This is a review paper on the crystal chemical approach to research on ceramic materials, many of mineralogic significance. Like many review papers, it is not easily readable. Background necessary: advanced inorganic chemistry and elementary mineralogy.

Sanderson, R.T. 1960. *Chemical periodicity.* Reinhold Publishing Corporation, New York: 330 p.

The first four chapters, covering 60 pages, are excellent supplementary reading for a course in geochemistry or crystal chemistry. Chapter I briefly describes the historical development of concepts of atomic structure, culminating in the quantum numbers and the relationship between electronic structure of atoms and chemical periodicity. Chapter II is devoted to chemical binding forces and development of the author's own unique "stability ratio" electronegativity. Chapter III applies the author's theory to a variety of topics, including bond polarity, bond length, and bond energy; hybrid bonding is also discussed. Chapter IV treats coordination chemistry, including topics like complex ions, radius ratio rules, chelation, ligand field theory. These chapters are brief, but meaty, and highly readable. They are a good survey of inorganic chemistry basic to crystal chemistry. The author's treatment provides an insight into the concept of electronegativity. Background necessary: basic college chemistry.

Weast, R.C. (editor). 1969. *Handbook of chemistry and physics.* Chemical Rubber Publishing Company, Cleveland, Ohio. 2356 p.

Weyl, W.A., and E.C. Marboe, 1962. *The constitution of glasses. A dynamic interpretation. Vol. I. Fundamentals of the structure of inorganic liquids and solids.* Interscience Publishers [John Wiley & Sons], New York: 427 p.

The title is misleading. The first 200 pages are essentially a treatise on solid state chemistry and inorganic chemistry from a crystal chemical point of view. Some of the topics included are properties of cations and anions, ideal crystals, real crystals, structure of liquids, melting of crystals, nucleation and crystallization. The approach is non-mathematical, being based instead on the concepts of electronic screening and the mutual polarization and deformation of ions. Many of the examples deal with silicate systems. This book is particularly suitable for the person seeking a qualitative understanding of crystal chemistry and the mechanisms of solid state processes. Background necessary: basic college chemistry; physical chemistry helpful but not always necessary.

PHYSICAL CHEMISTRY

Ahmed, S.M. 1966. Studies of the dissociation of oxide surfaces at the liquid-solid interface. *Canadian Journal of Chemistry*, 44 (2): 1663-1670.

The dissociation of surface hydroxyl groups on crystalline SiO_2, ZnO_2, and ThO_2, in aqueous suspensions, has been studied as a function of pHs at different ionic strengths of KNO_3. The work is primarily aimed at deriving information on the nature of interactions at the interface from the double layer characteristics. Suitable for graduates and advanced undergraduates. Background necessary: physical chemistry and thermodynamics.

Ahrens, L.H. (editor). 1968. *Origin and distribution of the elements.* Pergamon Press Ltd., Oxford: 1178 p.

Arising from the 1967 Paris symposium of the same title, this extraordinary book encompasses the whole spectrum of geochemistry. Major topics treated include theories of origin of the elements, extraterrestrial abundances (in three sections: solar, stellar, and interstellar; meteorites; planets and minor bodies in the solar system) and terrestrial abundances. This book is excellent for advanced students interested in almost any aspect of geochemistry and is highly recommended for all professional geochemists. Background necessary: thorough knowledge of nuclear astrophysics, cosmology, meteoritics; petrology or rare-earth chemistry would be useful. Quality of presentation and logical development is uneven but generally high.

Anderson, G.M. 1964. The calculated fugacity of water to 1000°C and 10,000 bars. *Geochimica et Cosmochimica Acta*, 28 (5): 713-715.

Suitable for graduates and advanced undergraduates. Background necessary: thermodynamics and physical chemistry.

Blount, C.W., and F.W. Dickson. 1969. The solubility of anhydrite ($CaSO_4$) in NaCl-H_2O from 100 to 450°C

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and 1 to 1000 bars. *Geochimica et Cosmochimica Acta*, 33 (2): 227-245.

The response of anhydrite solubility to changing conditions of temperature, pressure, and NaCl concentration is determined in the laboratory. The results are compared with previous work. This paper presents some insights into the processes responsible for the transport of the components of anhydrite in natural solutions and the deposition of anhydrite in nature. Suitable for advanced undergraduates and graduates. Background necessary: basic college chemistry.

Bowen, N.L. 1956. *The evolution of the igneous rocks*. Dover Publications, Inc., New York: 332 p.

Portions of this book contain classic examples of the application of basic thermodynamics to problems of mineral equilibria, phase diagrams, etc. Some of the petrology is a little out-dated but the chemical applications are clear and valid.

Brancazio, P.J., and A.G.W. Cameron (editors). 1964. *The origin and evolution of atmospheres and oceans*. John Wiley and Sons, Inc., New York: 314 p.

Topics in this volume range from the gas content of meteorites, atmospheres of planets other than the earth, and processes by which volatiles escape from the earth's interior, to the chemical, physical, and biologic reactions by which the atmosphere and oceans evolve. A valuable feature is the reprinting, as chapter 1, of W.W. Rubey's classic 1951 paper, "Geologic history of sea water." Juxtaposition of chapters written by scientists with very diverse backgrounds and interests, dealing with different aspects of a common problem, makes the book of interest to students of the philosophy and history of scientific thought as well as to geochemists. It can be read with profit by students with various interests and levels of preparation, and because it is very clearly presented, with numerous well considered diagrams and useful tables, this book is well suited as the basis of a seminar for advanced undergraduates or first-year graduate students. Background necessary: basic college chemistry and physics (with calculus); the chemistry course should include an introduction to modern physical chemistry. Introductory geology and some knowledge of geophysics would be useful.

Burnett, D.S., W.A. Fowler, and Fred Hoyle. 1965. Nucleosynthesis in the early history of the solar system. *Geochimica et Cosmochimica Acta*, 29 (12): 1209-1241.

This paper revises the model of Fowler, Greenstein, and Hoyle for nucleosynthesis of D, Li, Be, and B by high energy particles from the sun during the early history of the solar system. Suitable for specialized advanced courses. Background necessary: physical chemistry, atomic physics, advanced mathematics.

Burns, R.G., and W.S. Fyfe. 1966. Distribution of elements in geological processes. *Chemical Geology*, 1 (1): 49-56.

The generally accepted rules of Goldschmidt, modified by Ringwood and Ahrens, concerning element distribution in geologic processes and the controlling atomic properties, are considered to lack generality and may fail to predict actual behavior. "The behavior of transition elements frequently reflects crystal-field influences which are a function of the chemistry and structural states of the systems considered and in many cases observed trends may be explained by crystal-field theory. These considerations indicate that the magnitude and direction of fractionation of some element pairs may be radically changed in different chemical systems and existing rules cannot describe such changes." Suitable for graduates and advanced undergraduates. Background necessary: college chemistry and elementary thermodynamics.

Cloke, P.L. 1963. The geologic role of polysulfides -- Part I. The distribution of ionic species in aqueous sodium polysulfide solutions. *Geochimica et Cosmochimica Acta*, 27 (12): 1265-1298.

"Numerous measurements have been made of the pH, Eh, and the potential of a silver-silver sulfide electrode in sodium sulfide and sodium potassium polysulfide solutions. By suitably estimating the second dissociation constant of hydrogen sulfide and various activity coefficients, it has been possible to derive a consistent model for the distribution of the polysulfide and sulfide S^{-2}, S_4^{-2}, S_5^{-2}, S_6^{-2} and HS^{-1}, at strengths up to 1 M and for pH values between 7 and 13." This model differs markedly from previous models. Suitable for graduates and advanced undergraduates. Background necessary: solution chemistry and calculus.

Curie, P. 1885. Sur la formation des cristaux et sur les constantes capillaires de leurs differentes faces. *Bulletin de la Société Mineralogique de France*, 8: 145-150.

A brief but elegant treatment of relationships between surface energy and morphology of ideal

crystals. Background necessary: a reading knowledge of French and high school algebra.

Duffy, J.K., N.O. Smith, and Bartholomew Nagy. 1961. Solubility of natural gases in aqueous salt solutions. I. Liquidus surfaces in the system CH_4-H_2O-$NaCl_2$-$CaCl_2$ at room temperature and at pressures below 1000 psia. *Geochimica et Cosmochimica Acta*, 24 (1): 23-31.

"The solubility of methane in water, in aqueous solutions of sodium chloride, calcium chloride, and both sodium and calcium chloride has been determined at room temperatures and at pressures up to 1000 psia by the pressure decline method. The results for water agree with previous published values, but the solubilities in the salt solutions are considerably higher. The data obtained, augmented by other solubility figures from the literature, permit the construction of the liquidus surfaces in the tetrahedral phase model for the system CH_4-H_2O-NaCl-$CaCl_2$ at fixed temperature and pressure. An orthogonal projection of these surfaces is presented." Suitable for graduates and advanced undergraduates. Background necessary: solution chemistry and familiarity with phase diagrams.

Eggers, D.F., Jr., N.W. Gregory, G.D. Halsey, Jr., and B.S. Rabinovitch. 1964. *Physical chemistry*. John Wiley and Sons, New York: 783 p.

This book is a standard college text on physical chemistry with slightly more emphasis on quantum mechanics than usual. The authors consider such topics as quantum mechanical energy levels, statistical mechanics, gases, thermodynamics, phase equilibria, solutions, and kinetics. Background necessary: basic college chemistry and mathematics through calculus.

Eisenman, George, J.P. Sandblom, and J.L. Walker, Jr. 1967. Membrane structure and ion permeation. *Science*, 155 (3765): 965-974.

A variety of membranes can be constructed whose structures are well defined and whose permeation mechanisms and particular parameters can be varied in a controlled manner. By correlating structure and ion permeation in such membranes it should be possible to develop experimental criteria for determining the structure, and hence the mechanism, of ion permeation through an unknown membrane. In an attempt to develop these criteria, the authors have examined such variables as the presence or absence of ion exchange sites, their fixation or freedom of motion, their degree of dissociation, and the extent to which their chemical properties depend on external forces. Suitable for graduates and advanced undergraduates. Background necessary: physical chemistry.

Ellis, A.J., and N.B. Milestone. 1967. The ionization constants of hydrogen sulfide from 20 to 90°C. *Geochimica et Cosmochimica Acta*, 31 (4): 615-620.

The first and second ionization constants for hydrogen sulfide have been determined from 20 to 90°C by a spectrophotometric method. Suitable for graduates and advanced undergraduates. Background necessary: basic physical chemistry.

Faust, S.D., and J.V. Hunter (editors). 1967. *Principles and applications of water chemistry*. [Proceedings of the Fourth Rudolfs Research Conference, Rutgers, The State University, New Brunswick, New Jersey]. John Wiley and Sons, Inc., New York: 643 p.

This volume hopes "to create an awareness that chemical principles can be and should be applied to the practical technology of water and wastewater treatment" and provides "a hint of the chemistry of natural aqueous environments." The authors represented include some of the leaders in the fields of chemistry and geochemistry. The conference was organized with one author expounding a principle (*e.g.* electrical phenomena at surfaces; mineralogic factors in natural water equilibria; metal ions in aqueous solution) and the following two or three authors discussing applications of that principle (*e.g.* electrokinetic characteristics of silicic surfaces, geochemical control of solubility of aqueous silica, equilibrium chemistry of iron in ground water, respectively). Other principles that are dealt with are: reaction rates in solution; physical absorption on solids; and factors determining chemical oxidation and reduction in solution. Suitable for graduates and advanced undergraduates. Background necessary: varies with topics.

Fudali, R.F. 1965. Oxygen fugacities of basaltic and andesitic magmas. *Geochimica et Cosmochimica Acta*, 29 (9): 1063-1075.

This paper is a basic discussion of the role of oxygen pressure in the development of igneous rocks. Basic thermodynamic principles underlying the petrologic conclusions are discussed in detail.

Goldsmith, J.R. 1967. Metastability and hangovers in crystals. *Geochimica et Cosmochimica Acta*, 31 (6): 913-919.

The author presents a discussion of the processes of nucleation and crystal growth, in the broadest sense, and the effect that these processes have on the physical and structural state of the resulting crystals and on their chemical compositions. Suitable for graduates and advanced undergraduates. Background necessary: basic physical chemistry.

Greenwood, H.J. 1967. The *N*-dimensional tie-line problem. *Geochimica et Cosmochimica Acta*, 31 (4): 465-490.

"An analytical method is presented for determining whether two mineral assemblages can be related to one another by a balanced chemical reaction or whether their differing mineralogies must be attributed to differing bulk compositions. Projections and other chemographic methods are shown to be equivalent but less general than the method presented. Set theory and vector algebra are used to state the problem and to formulate a solution. Solutions are reached by the methods of linear programming and result in balanced chemical reactions, if such exist." Open and closed systems can be equally well treated, as can various projections, and numerous idealized and natural examples are presented to illustrate the analytic method. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry and mathematics to set theory and vector analysis.

Grover, J.E., and P.M. Orville. 1969. The partitioning of cations between coexisting single- and multi-site phases with application to the assemblages: orthopyroxene-clinopyroxene and orthopyroxene-olivine. *Geochimica et Cosmochimica Acta*, 33 (2): 205-226.

It is shown that the form of the function describing partitioning between a single-site phase and a phase containing two or more energetically distinct sites can be deduced from the cation exchange free energies between pairs of sites, and conversely that the cation exchange free energies between pairs of sites can, in some cases, be deduced explicitly from the form of the partitioning curve. A theoretical model is developed for partitioning between coexisting single- and double-site phases and expressions for the free energies of inter- and intracrystalline cation exchange.
The double-site phase is considered in terms of a familiar mixing model and two natural examples of coexisting mineral pairs are considered in light of the theoretical relations presented. Suitable for graduate level courses. Background necessary: physical chemistry and thermodynamics. Presentation is concise, with suitable figures.

Harned, H.S., and B.B. Owen. 1958. *The physical chemistry of electrolytic solutions* (Third Edition). Reinhold Publishing Corporation, New York: 803 p.

This is a basic reference for many of the equations and concepts used in solution geochemistry. The authors consider such topics as interionic attraction, thermodynamic properties of aqueous solutions, irreversible processes, conductance, diffusion, coulomb forces, activities, and thermochemical quantities. Background necessary: basic college chemistry, physical chemistry, mathematics through calculus.

Helgeson, H.C. 1967. Thermodynamics of complex dissociation in aqueous solution at elevated temperatures. *Journal of Physical Chemistry*, 71 (3): 3121-3136.

The temperature dependence of the thermodynamics of dissociation for complexes in the temperature range 0 to 370°C is described in terms of functions involving the dielectric constant of water and a power series consistent with nonelectrostatic interaction in the absence of a dielectric medium. Evaluation of the theoretical equations for various reactions yields results in close agreement with published thermodynamic data. Heat capacities of dissociation may vary monotonously with temperature or may pass through extremes, depending on the relative influences of electrostatic and nonelectrostatic interaction on the stabilities of the complexes as temperature increases. When the dielectric constant of the solvent becomes small at high temperatures, the electrostatic contribution dominates. As a consequence, many complexes become significantly stable at high temperatures, and the enthalpies, entropies, and heat capacities of dissociation become relatively large negative numbers. Suitable for graduates and advanced undergraduates. Background necessary: thermodynamics.

Helgeson, H.C. 1968. Evaluation of irreversible reactions in geochemical processes involving minerals and aqueous solutions -- I. Thermodynamic relations. *Geochimica et Cosmochimica Acta*, 32 (8): 853-877.

This paper provides a summary of thermodynamic relations pertinent to evaluating geochemical processes that involve aqueous solutions. The theme is that equilibrium models reduce to nonlinear equations that can be evaluated only by indirect and unwieldy analytic methods, whereas, by contrast, the differential equations describing an irreversible process are all linear, which makes possible rapid computations. With

part II, this is an important paper for advanced undergraduate and graduate courses. Background necessary: physical chemistry, thermodynamics, and mathematics to linear differential equations.

Helgeson, H.C., R.M. Garrels, and F.T. Mackenzie. 1969. Evaluation of irreversible reactions in geochemical processes involving minerals and aqueous solutions -- II. Applications. *Geochimica et Cosmochimica Acta*, 33 (4): 455-481.

"Equilibrium relations among common rock-forming minerals and aqueous solutions over a range of temperatures and pressures are known experimentally for a number of systems and can be calculated for others. This information permits prediction of the mass transfer involved in chemical reactions characteristic of geochemical processes. Calculations of this kind are used to examine various chemical and geological implications of irreversibility in idealized models of weathering, evaporite concentration, diagenesis, hydrothermal rock alteration, and ore deposition." With part I, this is an important paper for advanced undergraduate and graduate courses. Background necessary: physical chemistry and thermodynamics.

Holm, J.L., O.J. Kleppa, and E.F. Westrum, Jr. 1967. Thermodynamics of polymorphic transformations in silica. Thermal properties from 5 to 1070°K and pressure-temperature stability fields for coesite and stishovite. *Geochimica et Cosmochimica Acta*, 31 (12): 2289-2307.

"Cryogenic heat-capacity measurements on coesite and stishovite provide thermodynamic properties from 5 to 350°K." The heat capacities (Cp), entropies (S^0), and Gibbs energy functions $[-(G^0-H_0)/T]$ were determined. "Enthalpies of transition for phase changes were determined by solution calorimetry in a lead-cadmium-borate solvent at 697°C...The enthalpy of coesite to 1070°K and the enthalpy of transformation for stishovite-silica glass were provided by means of a novel technique, 'transposed-temperature' drop calorimetry. These data permit the delineation of P-T field phase boundaries for the stable equilibria coesite-quartz and coesite-stishovite, as well as for the metastable quartz-stishovite boundary, which are in reasonable agreement with the results of recent equilibrium and formation studies." Suitable for graduates and advanced undergraduates. Background necessary: physical chemistry, thermodynamics, integral calculus.

Jastrow, Robert, and A.G.W. Cameron (editors). 1963. *Origin of the solar system.* Academic Press, New York: 176 p.

This book is a broad treatment of theories of and evidence pertaining to solar system origin, as they stood in early 1962. Contributions from astrophysicists, meteoriticists, and a geophysicist bring the reader into contact with most of the fundamental problems in the field, many of which are still of great interest. The editors have succeeded in presenting a well balanced and logical sequence of papers; the historical review by Ter Haar and Cameron is especially valuable. Very good as an introduction to questions of solar system origin for advanced students and highly motivated undergraduates, although several of the chapters are noticeably out of date. Background necessary: basic college chemistry and physics (with calculus), physical chemistry, and some knowledge of astronomy; geophysics would be useful. The text is very clearly presented, with numerous helpful diagrams and several excellent photographs.

Kern, Raymond, and Alain Weisbrod. 1967. *Thermodynamics for geologists.* Freeman, Cooper and Company, San Francisco: 304 p.

This book provides a sound introduction and examination of the application of chemical thermodynamics to geological problems. The text discussion is kept geologically relevant through the use of many examples of thermodynamic calculations based on experimental data from minerals and mineral assemblages. The book would be excellent for senior year or graduate level courses. Background necessary: basic college calculus, introductory physical chemistry, mineralogy or petrology.

Korzhinskii, D.S. 1966. On thermodynamics of open systems and the phase rule (A reply to D.F. Weill and W.S. Fyfe). *Geochimica et Cosmochimica Acta*, 30 (8): 829-835.

"The properties of the thermodynamic potentials of systems with perfectly mobile components are considered in relation to the critical remarks of Weill and Fyfe (1964), as well as the possibilities of the application of the Gibbs phase rule in petrology." Suitable for graduates and advanced undergraduates. Background necessary: physical chemistry including thermodynamics. The paper is written for an audience familiar with this field.

Krauskopf, K.B. 1967. *Introduction to geochemistry.* McGraw-Hill Book Company, New York: 721 p.

Krauskopf's book is one of the best texts available for a general geochemistry course. The author

covers a broad range of topics from solution chemistry to crystal chemistry and from low- to high-temperature geochemistry. The text is the outgrowth of the author's lectures on geochemistry. It is well written and on a level appropriate to the average science major in his junior or senior year. The book is unique among geochemistry texts in that it provides problems at the end of each chapter (answers to some in back). Thus the reader can immediately judge his ability to apply the concepts. The author was wise in presenting a low-level treatment of thermodynamics in the main text and a more rigorous treatment as an appendix. The book's strongest topics are low-temperature and solution chemistry and phase equilibria. Helpfully, it contains annotated bibliographies. Background necessary: physical geology and basic college chemistry and mathematics.

Kretz, Ralph. 1961. Some applications of thermodynamics to coexisting minerals of variable composition. Examples: orthopyroxene-clinopyroxene and orthopyroxene-garnet. *Journal of Geology*, 69 (4): 361-387.

This paper is probably the pioneering study of the distribution coefficients in the study of metamorphic mineral assemblages. The author outlines the use of these coefficients in determining temperatures of formation of mineral assemblages.

Langmuir, Donald. 1968. Stability of calcite based on aqueous solubility measurements. *Geochimica et Cosmochimica Acta*, 32 (8): 835-851.

The paper presents a critical reevaluation of existing solubility data for calcite at 25°C in pure water at 1 atm pressure; it is the first of several articles by Langmuir and Waldbaum on stability relations of calcite and aragonite. "The study includes a detailed appraisal of the various errors relating to the solubility measurements and their interpretation." Suitable for graduates and advanced undergraduates. Background necessary: physical chemistry.

Macwood, G.E., and F.H. Verhoek. 1961. How can you tell whether a reaction will occur? *Journal of Chemical Education*, 38 (7): 334-337.

This article offers an excellent exposition of the concepts of enthalpy, entropy, and free energy as they are individually and collectively related to the spontaneity of a chemical reaction. Good examples are given to show why the heat of reaction is insufficient to predict whether or not a reaction will occur. The authors provide a helpful discussion of the concept of entropy. This paper is written at an introductory level and is outstanding in its clarity. Background necessary: basic college chemistry.

Marshall, C.E. 1956. Thermodynamic, quasithermodynamic, and non-thermodynamic methods as applied to the electrochemistry of clays. *In* Ada Swineford (editor). *Clays and clay minerals -- proceedings of the fourth national conference on clays and clay minerals*. National Academy of Sciences, National Research Council Publication 456: 288-300.

The consequences of nonhomogeneous charge distribution in clay systems are examined. Potentiometric methods of measurement, with (quasithermodynamic) and without (thermodynamic) liquid functions are compared. The former afford data which can be interpreted directly in terms of single ions; the latter give chemical potentials of soluble molecular species or ratios of mean activities, neither of which afford a characterization of single cations in relation to clay surfaces. Cataphoresis results are shown to be in agreement with conductance and potentiometric data for dilute clay systems. Suitable for graduates and advanced undergraduates. Background necessary: clay mineralogy, basic physical chemistry, thermodynamics.

McIntire, W.L. 1963. Trace element partition coefficients -- a review of theory and applications to geology. *Geochimica et Cosmochimica Acta*, 27 (12): 1209-1264.

The thermodynamics of trace element partition among coexisting phases is reviewed. Particular attention is paid to partition between crystalline solids and coexisting liquid phases. Subheadings include: modes of occurrence of trace elements; tendency for solid solution formation; thermodynamics of dilute solid solution formation; variation of partition coefficient with composition of the solid phase; variation of partition coefficient with pressure; variation of partition coefficient with temperature; effect of difference in valence on partition coefficient; partition of trace elements between solid phases; the logarithmic distribution law; geological thermometry and barometry; criteria for equilibrium; isotherms and isobars in metamorphic terranes; trace element distribution during crystallization of a magma; origin of granite bodies; trace element distribution during the separation of an aqueous phase from a magma; composition of ore-forming fluid; trace element distribution during the precipitation of an evaporite sequence; determination of paleosalinity; guides to mineral deposits; problems in the geochemistry of the individual elements. Suitable for graduates and advanced undergraduates. Background necessary: physical chemistry and thermodynamics. This paper is a comprehensive review with a large reference list.

Mueller, R.F. 1961. Analysis of relations among Mg, Fe and Mn in certain metamorphic minerals. *Geochimica et Cosmochimica Acta*, 25 (4): 267-296.

"Existing data on the distribution of Mg, Fe and Mn among coexisting metamorphic actinolites, cummingtonites, Ca-pyroxenes, and orthopyroxenes, are examined in terms of theoretical solution models applicable to binary and ternary solid solutions...Certain observed invariant relations of the distribution functions are also interpreted in terms of the multicomponent systems...The data are also examined with a view of detecting the elemental source of certain deviations in the atomic fractions which might be attributed to errors in the chemical analyses or to failure of a given element to attain equilibrium...In addition, the structural-energetic basis for the thermodynamic functions is discussed in terms of the crystal structure of cummingtonite." Suitable for graduates and advanced undergraduates. Background necessary: basic physical chemistry, thermodynamics, phase rule. The presentation helpfully includes seventeen diagrams.

Mueller, R.F. 1962. Energetics of certain silicate solid solutions. *Geochimica et Cosmochimica Acta*, 26 (May): 581-598.

"The energetics of homogeneous intracrystalline (order-disorder) equilibria of amphiboles and pyroxenes are discussed in a quantitative manner. The distributions of Mg and Fe^{2+} among the lattice sites of cummingtonite and orthopyroxene are derived from the functions of the heterogeneous ion exchange equilibria for coexisting cummingtonite-actinolite and Ca-pyroxene-orthopyroxene. The derived distribution in cummingtonite is in good agreement with that obtained by X-ray diffraction by Ghose." The distribution in other pyroxenes is also discussed. "The general problem of the distribution of elements is discussed in relation to various types of intracrystalline equilibria coupling effects between different types of ions and types of polyhedra of coordination with the cations." Suitable for graduates and advanced undergraduates. Background necessary: basic physical chemistry, thermodynamics, phase rule.

Ramberg, Hans. 1964. Chemical thermodynamics in mineral studies. *In* L.H. Ahrens, Frank Press, and S.K. Runcorn (editors). *Physics and chemistry of the earth*, v. 5. The Macmillan Company, New York: 225-252.

This article is concerned with the calculation of equilibrium conditions for mineral systems. The section headings give an idea of its scope: examples on calculation of chemical equilibrium among minerals based on thermochemical data; reactions in which mix-crystals participate; the effect of hydrostatic pressure on mineral reactions; reactions involving jadeite and albite; the transition olivine structure-spinel structure; example on estimation of heat of formation of a silicate from experimental phase equilibrium data; free energy as a function of anisotropic stress; and mineral equilibrium at partial fluid pressure different from total pressure. Suitable for graduates and advanced undergraduates. Background necessary: an introductory thermodynamics course.

Rapoport, S.I. 1965. Ionic accumulation by water flow through a membrane. *Acta Physiologica Scandinavica*, 64: 361-371.

"A cell model was constructed, consisting of two compartments, separated by a membrane in which the gradients of hydrostatic pressure and of concentration could be produced. K^+ and Li^+ were chosen as representative ions because of the difference between their mobilities. Three membrane factors affecting ionic accumulation are discussed: (1) charge and selectivity; (2) ionic mobility within the membrane; and (3) water flow effects. Steady state accumulation as well as the net flux in the non-steady state are analyzed." Suitable for graduates and advanced undergraduates. Background necessary: physical chemistry.

Ryabchikov, I.D. 1965. Behavior of trace elements during phase separation. *Geochemistry International*, 2 (1): 163-170.

"Theoretical equations for the variation and distribution of trace components during equilibrium and fractional crystallization are presented, and in the latter case are modified to take into account the possible separation of fugitive phases. Application to the Mn-poor portion of the system Mg_2SiO_4-Fe_2SiO_4-Mn_2SiO_4 indicates the likelihood of maximum Mn concentrations in olivines separating during medial stages of the crystallization process. The greater variability of trace-element contents in mafic igneous complexes than in granitic ones is attributed to the greater temperature range of crystallization of the mafic rocks." Suitable for graduates and advanced undergraduates. Background necessary: basic physical chemistry and thermodynamics.

Schenk, J.E., and W.J. Weber, Jr. 1968. Chemical interactions of dissolved silica with iron II and III. *Journal of the American Water Works Association*, 60 (2): 199-212.

This article describes some of the results of an investigation of several of the reactions of dissolved silica in dilute solution. Subjects dealt with include: solubility relationships; polymerization; silica-

metal ion interactions; oxidation of iron II; rates of oxidation; catalytic effect of silica; hydrolysis of iron III. Suitable for graduates and advanced undergraduates. Background necessary: physical chemistry.

Schwarcz, H.P. 1967. The effect of crystal field stabilization on the distribution of transition metals between metamorphic minerals. *Geochimica et Cosmochimica Acta*, 31 (4): 503-517.

"The distribution of transition-metal ions between silicate minerals of metamorphic rocks has been analyzed from the stand-point of crystal field theory. It is found that the order of distribution coefficients of ions of the same charge between two phases is partly determined by the relative crystal field stabilization energy (CFSE) of the ions." The effect of the ionic radius is compared with CFSE and estimated to be smaller. "Use of CFSE values may lead to prediction of temperature dependence of trace-element partition coefficients." Suitable for graduates and advanced undergraduates. Background necessary: crystal chemistry and thermodynamics.

Sippel, R.F. 1963. Sodium self diffusion in natural minerals. *Geochimica et Cosmochimica Acta*, 27 (1): 107-120.

"Sodium self-diffusion coefficients in the range 10^{-9} - 10^{-11} cm^2/sec have been measured in a group of natural sodium-containing minerals. Sodium mobility is found to decrease in the order analcite, obsidian, cryolite, sodalite, nepheline, microcline, albite, orthoclase, acmite." Sodium mobility in silicates is investigated with respect to valence electron density, oddities in structure, and the resistance to diffusion of species other than sodium. A factor of merit is defined [(valence electron density X fusing temperature) /10] which should increase with increasing diffusion resistance. The factor of merit has geochronological applications. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry and mathematics to calculus.

Slaughter, Maynard. 1966. Chemical binding in silicate minerals. Part I. Model for determining crystal-chemical properties. *Geochimica et Cosmochimica Acta*, 30 (3): 299-313.

"The relations of chemical bond types and configuration to expected physico-chemical behavior of silicates are outlined. Combining coulomb energies with appropriate corrections makes possible quantitative prediction of stability relations of minerals. Melting temperatures of spinel have been calculated from the binding energies." Suitable for graduate and advanced undergraduate courses. Background necessary: physical chemistry, thermodynamics, mathematics to integral calculus, and crystal chemistry.

Slaughter, Maynard. 1966. Chemical binding in silicate minerals. Part II. Computational methods and approximations for the binding energy of complex silicates. *Geochimica et Cosmochimica Acta*, 30 (3): 315-322.

Computational techniques used for finding the Coulomb energy and its derivatives are the Ewald method for lattice sums and differential Fourier synthesis. "Computations are carried out for all symmetrically independent atoms in the unit cell. Repulsion energies and their derivatives are calculated using simple exponential terms. Covalency in the bonds is taken into account by reducing charges on ions for the Coulomb energy terms. By using differentials of energy terms, equations are given for shifting atoms to minimum energy positions." Suitable for graduate and advanced undergraduate courses. Background necessary: physical chemistry, crystal chemistry, thermodynamics, mathematics to differential Fourier synthesis.

Slaughter, Maynard. 1966. Chemical binding in silicate minerals. Part III. Application of energy calculations to the prediction of silicate mineral stability. *Geochimica et Cosmochimica Acta*, 30 (3): 323-339.

"Melting and decomposition temperatures of some minerals including corundum and quartz have been calculated from the binding energies. Agreement between calculated and observed melting points of minerals is exceptionally good when covalency, radius ratio, and coordination effect corrections are made to the melting points determined from Coulomb binding energies. Thermal stabilities of some phyllosilicates are predicted semiquantitatively. Calculated energies show that the stability of montmorillonite with respect to other phyllosilicates in most low-temperature geochemical environments is probably the result of hydration of the inter-layer space. Also, when small amounts of magnesium are present in a silicate system, montmorillonite is the phase which minimizes the total energy of the system." Suitable for graduate and advanced undergraduate courses. Background necessary: physical chemistry, crystal chemistry, thermodynamics.

Stokes, R.H., and R.A. Robinson. 1966. Interactions in aqueous nonelectrolyte solutions. I. Solute-solvent equilibria. *Journal of Physical Chemistry*, 70 (7): 2126-2131.

Solutes which interact with the solvent by a series of solvation equilibria to form species which mix according to the ideal solution law are considered. General expressions relating the solvent activity to the molality and the equilibrium constants are given. Sucrose solutions can be described with considerable accuracy by the assumption of a number of possible solvation sites equal to the number of oxygen atoms in the solute molecule, with a single equilibrium constant given the same value for each site. Mixed solutions of several solutes conforming to this model are shown to obey very simple equations relating the molalities to isopiestic equilibrium between solutions of the separate and mixed solutes. A similar relation between the activity coefficients is given. Examples of systems which conform to these mixture relations are given, and it is suggested that cases of large departures from the relation may be taken as evidence of specific solute-solvent interaction. Suitable for graduates and advanced undergraduates. Background necessary: physical chemistry.

Toulmin, Priestley, III, and P.B. Barton, Jr. 1964. A thermodynamic study of pyrite and pyrrhotite. *Geochimica et Cosmochimica Acta*, 28 (5): 641-671.

The electrum-tarnish method is used to find an equation that interrelates the composition of pyrrhotite fugacity of sulfur and temperature. The same method also permits the determination of the f_{S_2} vs. T curve for the univariant assemblage pyrrhotite-pyrite vapor from 743 to 325°C. "The activity of FeS in pyrite-saturated pyrrhotite is very different from unity, a fact that greatly influences the interpretation of some phase equilibrium studies involving pyrrhotite and their application to sulfide mineral assemblages, but has little effect on the more general calculations of composition of hydrothermal or magmatic fluids. Pressure effects calculated from available volumetric data on the phases are small." Suitable for graduates and advanced undergraduates. Background necessary: thermodynamics and phase rule.

Waldbaum, D.R. 1969. Thermodynamic mixing properties of NaCl-KCl liquids. *Geochimica et Cosmochimica Acta*, 33 (11): 1415-1427.

The excess Gibbs energies and entropies of mixing of NaCl-KCl liquids have been calculated using previously derived mixing parameters of the crystalline solutions and the temperature and composition of the minimum (657°C, 48.5 mole % KCl) in the melting region. Margules parameters of the liquid based on the present formulation differ by 1 kcal at 800°C from the values obtained in electrochemical studies. Solidus and liquidus curves calculated from these results are compared with experimental data from 12 previous studies of the melting region.

"Alkali buffer potentials, ($\mu K - \mu Na$) in this system, calculated from the mixing properties of the liquid, range from -14.6 ± 0.5 kcal at 796°C ($N_{KCl} \approx 0$), to -5.90 ± 0.05 kcal at the minimum, to +7.6 ± 0.5 kcal at 770°C ($N_{KCl} \approx 1$)."

Suitable for graduates and advanced undergraduates. Background necessary: physical chemistry.

Weeks, W.F. 1956. A thermochemical study of equilibrium relations during metamorphism of siliceous carbonate rocks. *Journal of Geology*, 64 (3): 245-270.

This paper is a basic study of heats and entropies of reactions with their applications to prediction of equilibrium mineral assemblages.

Weill, D.F., and W.S. Fyfe. 1964. A discussion of the Korzhinskii and Thompson treatment of thermodynamic equilibrium in open systems. *Geochimica et Cosmochimica Acta*, 28 (5): 565-576.

It is suggested that the new phase rule of Korzhinskii and Thompson "is an undesirable statement of the Gibbs phase rule which presents temptation for misrepresentation of the nature and limitations of the phase rule in petrologic analysis." Suitable for graduates and advanced undergraduates. Background necessary: thermodynamics and phase rule.

Weill, D.F., and W.S. Fyfe. 1964. The solubility of quartz in H_2O in the range 1000-4000 bars and 400-550°C. *Geochimica et Cosmochimica Acta*, 28 (8): 1243-1255.

The solubility of quartz in H_2O in the range indicated in the title has been measured and two rate studies made at 400 and 625°C. Using data from these studies, thermodynamic calculations suggest that the then widely accepted reaction for the solution of quartz, SiO_2 (qtz) + $2H_2O \rightleftarrows Si(OH)_4$, may be inadequate to represent the heterogeneous equilibrium between quartz and solution over a wide range of temperature and pressure. Suitable for graduates and advanced undergraduates. Background necessary: physical chemistry, thermodynamics, calculus.

Weill, D.F., and W.S. Fyfe. 1967. On equilibrium thermodynamics of open systems and the phase rule (A reply to D.S. Korzhinskii). *Geochimica et Cosmochimica Acta*, 31 (7): 1167-1176.

This paper is a reply to comments by Korzhinskii (1966) on the authors' earlier (1964) discussion of Korzhinskii's (1957) paper "Physicochemical basis of the analysis of the paragenesis minerals" (Consultants Bureau, Inc.). Suitable for graduates specializing in the field. Background necessary: physical chemistry and thermodynamics.

Zen, E-An. 1962. Problem of the thermodynamic status of the mixed-layer minerals. *Geochimica et Cosmochimica Acta*, 26 (October): 1055-1067.

"Minerals that show mixed layering, particularly with the component layers in random sequence, pose problems because they may behave thermodynamically as single phases or as polyphase aggregates. Two operational criteria are proposed for their distinction." Suitable for graduates and advanced undergraduates. Background necessary: clay mineralogy and thermodynamics.

ZoBell, C.E. 1946. Studies on redox potential of marine sediments. *American Association of Petroleum Geologists Bulletin*, 30 (4): 477-513.

This is a classic and fundamental paper on mineral equilibrium in sediments. The author provides a thorough explanation of redox potentials and pH, and of their applications to sedimentary geochemistry.

KINETICS

Chalmers, Bruce. 1964. *Principles of solidification.* John Wiley and Sons, Inc., New York: 319 p.

This is an undergraduate textbook for metallurgists. Because of the emphasis on metals and their technology, much of this book is directed toward the special case in which growth is limited only by the rate at which heat can be transferred away from the melt-crystal interface. Nevertheless, the treatments of melt-crystal equilibrium, atomic processes, and nucleation are pertinent to both mineralogy and petrology, and the textbook style makes easy reading.

Christian, J.W. 1965. *The theory of transformations in metals and alloys.* Pergamon Press, Oxford: 975 p.

This advanced treatise is the most complete treatment available of the kinetics of phase transformations. Although the book is directed specifically toward transformations in metals, the theoretical treatments of crystal geometry, reaction rate theory, irreversible thermodynamics, grain boundaries, solid state diffusion, nucleation, crystal growth, and precipitation from solid solution are equally applicable to minerals. The references are well chosen and current through 1962. This book is difficult reading, highly mathematical, and definitely not for a beginner in the field!

Doremus, R.H., B.W. Roberts, and David Turnbull. 1958. *Growth and perfection of crystals.* John Wiley and Sons, Inc., New York: 609 p.

This volume contains the proceedings of an International Conference on Crystal Growth. The special significance of this conference is that it was held a few years after F.C. Frank proposed his brilliant solution to the problem of crystal growth kinetics first posed by J.W. Gibbs in his classic 1878 paper on heterogeneous equilibrium. This volume accordingly contains a wealth of beautifully illustrated data resulting from the flurry of research that followed Frank's paper. There are spectacular photos of whiskers, dendrites, spirals, and other growth forms in a variety of materials along with much quantitative data.

Fine, M.E. 1964. *Introduction to phase transformations in condensed systems.* The Macmillan Company, New York: 133 p.

This book is an introduction to the study of the kinetics and mechanisms of phase transformation in solids. It is written for metallurgists since most of the development of this subject has come from metallurgy; however, the principles and many of the experimental techniques are applicable to geologic materials as well. The author presumes a familiarity with thermodynamics, the processes of atomic motion in crystals, and intermediate-level mathematics. The excellent reference list is a welcome guide to the literature in this field.

Girifalco, L.A. 1964. *Atomic migration in crystals.* Blaisdell Publishing Company, New York: 162 p.

Girifalco presents an elementary but authoritative account of the motions of atoms and ions through solids. An understanding of the diffusion process is the first step toward understanding the kinetics and mechanisms of phase transformation in solids. This book is clearly written with an abundance of excellent illustrations.

Hanson, G.N., and P.W. Gast. 1967. Kinetic studies in contact metamorphic zones. *Geochimica et Cosmochimica Acta*, 31 (7): 1119-1153.

The effects of thermal metamorphism on mineral ages have been investigated near the contacts of two basic intrusives: from the Snowbank granitic stock near the contact with the Duluth Complex in Minnesota -- K-Ar ages of hornblende and Rb-Sr and K-Ar ages of biotite, muscovite, and potassium feldspar; from amphibolite near the contact with a quartz dolerite dike in the Beartooth Mountains of Wyoming -- K-Ar ages of hornblende and Rb-Sr and K-Ar ages of biotite. Suitable for graduates and advanced undergraduates. Background necessary: physical chemistry, thermodynamics, phase rule, mathematics to integral calculus.

Jackson, K.A., D.R. Uhlmann, and J.D. Hunt. 1967. On the nature of crystal growth from the melt. *Journal of Crystal Growth*, 1 (1): 1-36

This paper reviews the existing quantitative data on the kinetics of crystal growth from the melt and critically examines current theories in light of these data. Some prior acquaintance with the subject is assumed. Excellent photos show some typical growth morphologies.

Jensen, M.L. 1965. The rational and geological aspects of solid diffusion. *The Canadian Mineralogist*, 8 (3): 271-290.

The stated purpose of this paper is to set forth the basic principles of diffusion and to discuss the extent and importance of the mechanism in geologic phenomena. A rational mathematical treatment (Fick's first and second laws) of diffusion in minerals is shown to be available and of prime assistance in realizing the geological limitations of this mechanism. The conclusion is that solid diffusion is significant for relatively short distances (5 to 10 centimeters). Transport over considerably greater distances may be explained by more rapid movement through rock openings, along fracture zones, around mineral grains, and finally into crystals through flaws and breaks. Examples are given of the role of diffusion in such specific examples as rate of crystal growth, metamorphism, and metasomatic alteration and replacement. Suitable for graduates and advanced undergraduates. Background necessary: college chemistry and mathematics to calculus.

Knight, C.A. 1967. *The freezing of supercooled liquids.* D. Van Nostrand Company Inc., Princeton, New Jersey, Momentum Book 14: 145 p.

This book is an elementary and nonmathematical account of the nucleation and growth of crystals from a melt of the same composition. No prior background is assumed, and a complete, self-contained treatment is given of this simplest and most illustrative case of phase transformation kinetics. Water is the primary example, and hailstones, frost-heaving, and ice formation on lakes and ponds are among the problems discussed. A special feature is the chapter on simple experiments and home observation.

Mokady, R.S., and P.F. Low. 1966. Electrochemical determination of diffusion coefficients in clay-water systems. *Soil Science Society of America Proceedings*, 30 (4): 438-442.

The method of determination is based on electrochemical equations that are analogous to those commonly applied to aqueous solutions. A development of the relevant equations is given for clay-water systems. The method is used to determine diffusion coefficients of LiCl and NaCl in montmorillonite pastes. This method is presented as an alternative to Fick's law, but comparison of results from both methods is scheduled for a later publication. Suitable for graduates and advanced undergraduates. Background necessary: electrochemistry and mathematics to integral calculus.

Povoledo, D., and J.R. Vallentyne. 1964. Thermal reaction kinetics of the glutamic acid-pyroglutamic acid system in water. *Geochimica et Cosmochimica Acta*, 28 (5): 731-734.

This investigation is a continuation of earlier studies on the thermal reaction kinetics of amino compounds as related to paleobiochemistry. Suitable for graduates and advanced undergraduates. Background necessary: organic chemistry and kinetics.

Turnbull, David. 1956. Phase changes. *In* Frederick Seitz and David Turnbull (editors). *Solid state physics*, v. 3. Academic Press, New York: p. 225-306.

This paper is a comprehensive review of the thermodynamics and kinetics of phase changes by one of the leading contributors to the field. This article and its references provide the background assumed by more recent papers in the field.

Wollast, Roland. 1967. Kinetics of the alteration of K-feldspar in buffered solutions at low temperature. *Geochimica et Cosmochimica Acta*, 31 (4): 635-648.

"A study has been made of the release of Si and Al to solution from the alteration of a potassic feldspar in solutions buffered at pH values between 4 and 10." Suitable for graduates and advanced undergraduates. Background necessary: physical chemistry and mathematics to integral calculus.

APPLICATION OF CHEMICAL CONCEPTS TO HIGH-TEMPERATURE GEOLOGIC SYSTEMS

Arntson, R.H., F.W. Dickson, and George Tunell. 1960. Systems S-Na_2O-H_2O and S-H_2O: Application to the mode of origin of natural alkaline polysulfide and thiosulfate solutions. *American Journal of Science*, 258 (8): 574-582.

This paper presents the results of experimental studies on the systems and considers the possible modes of formation of alkaline polysulfide and thiosulfate solutions which may be capable of transporting certain ore-forming components under conditions which prevail at shallow depths in the Earth's crust. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry.

Barnard, W.M. 1967. Synthesis of pyrite from chloride-bearing solutions. *Economic Geology*, 62 (1): 138-147.

Experimental work shows that chloride-bearing solutions have the capability of transporting and depositing pyrite as a stable iron sulfide phase. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry.

Barnard, W.M., and P.A. Christopher. 1966. Hydrothermal synthesis of chalcopyrite. *Economic Geology*, 61 (5): 897-902.

Supporting evidence for the role of chloride solutions as possible agents in the formation of sulfide deposits is briefly reviewed. Experiments at or near 400°, 450° and 500°C showed that whereas water was completely ineffective in dissolving, transporting, and depositing chalcopyrite, saline solutions (2 and 4 molal sodium chloride) deposited amounts much greater than those needed to account for natural deposits of chalcopyrite. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry.

Barnard, W.M., and P.A. Christopher. 1966. Further study on the effectiveness of aqueous solutions in the hydrothermal synthesis of chalcopyrite. *Economic Geology*, 61 (7): 1287-1290.

The authors report further on experimental investigations of the possibility of synthesizing chalcopyrite from chloride-bearing and chloride-free solutions, comparing the effectiveness of various solutions in dissolving, transporting, and recrystallizing chalcopyrite. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry.

Barnes, H.L., S.B. Romberger, and Miroslav Štemprok. 1967. Ore solution chemistry II. Solubility of HgS in sulfide solutions. *Economic Geology*, 62 (7): 957-982.

The solubility of cinnabar (red HgS) in aqueous sulfide solutions was measured under varying conditions. Solubility constants were derived. The pH boundaries between regions of predominance of $HgS(H_2S)_2$, $Hg(HS)_3$, $HgS(HS)_2$, and HgS_2 were determined. Geologic implications are examined with respect to hot springs, hydrothermal transport, and deposition. Suitable for graduates and advanced undergraduates. Background necessary: solution chemistry and solution equilibria of minerals.

Cloud, P.E., Jr. 1968. Atmospheric and hydrospheric evolution on the primitive earth. *Science*, 160 (3829): 729-736.

This discussion focuses on the interactions that necessarily took place between biospheric, atmospheric, lithospheric, and hydrospheric evolution on the primitive earth and perhaps the moon. The questions examined

are the following: how can evidence and conjecture about each of these different kinds of evolution limit or illuminate hypotheses about the others; and how can all such lines of thought be integrated to bring us closer to a consistent and plausible model of early terrestrial events? Suitable for graduates and undergraduates. Background necessary: basic physical and biological sciences.

Fyfe, W.S., F.J. Turner, and John Verhoogen. 1958. *Metamorphic reactions and metamorphic facies.* Geological Society of America, New York, Memoir 73: 259 p.

This book presents a detailed discussion of selected topics in metamorphism. Chapter I (Turner) is a historical account of the development of the facies concept. A new definition of metamorphic facies is formulated. Chapters II to IV (Fyfe and Verhoogen), each of which ends with a summary in nontechnical language, deal with certain thermodynamic and kinetic aspects of metamorphic reactions. In chapter V, Fyfe and Turner correlate field and experimental data on the stability of critical mineral assemblages in metamorphic rocks. The role of water and heat in metamorphism is considered in chapter VI (Fyfe and Verhoogen). Chapter VII (Turner) is a revision of individual metamorphic facies. In light of new experimental and mineralogic data, the limits of some facies and subfacies are redefined and a few new divisions are proposed. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry and petrology; a knowledge of thermodynamics and kinetics will enable the reader to get even more out of the book.

Hawkins, D.B., and Rustum Roy. 1963. Distribution of trace elements between clays and zeolites formed by hydrothermal alteration of synthetic basalts. *Geochimica et Cosmochimica Acta*, 27 (7): 785-795.

This study is an attempt to determine the fractionation of various trace elements by the structure of the crystals forming. Gels and glasses of gross basaltic composition containing 0.5 percent by weight of boron, gallium, nickel, and strontium were treated hydrothermally in sealed systems at 350°C and 15,000 lb/in^2. The experiments were repeated introducing the trace elements into solution. The analcite and montmorillonite formed by this process were separated from each other, and each was analyzed for the above trace elements using emission spectrography. The main geological significance of this study is that distribution of the elements observed in the laboratory is similar to that observed in nature. This similarity indicates a potential usefulness of laboratory studies in investigations of certain aspects of element distribution which might be obscured in nature by processes that can be controlled in the laboratory. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry.

Hawkins, D.B., and Rustum Roy. 1963. Experimental hydrothermal studies on rock alteration and clay mineral formation. *Geochimica et Cosmochimica Acta*, 27 (10): 1047-1054.

"The alteration to clays and zeolites of a series of rock types varying in silica content has been studied under hydrothermal conditions below 425°C. Natural glassy and crystalline rocks and synthetic glasses and gels ranging from granitic to basaltic compositions have been reacted in sealed noble metal systems in CO_2-saturated, saline, acid, and basic environments." Observations were made from 240 hydrothermal runs. "...From the results of this and associated work it was concluded that clay minerals and zeolites are formed by reactions among monomeric silicate ions, aluminate ions, and metallic ions, resulting in the direct formation of the crystalline minerals." Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry.

Hemley, J.J. 1959. Some mineralogical equilibria in the system K_2O-Al_2O_3-SiO_2-H_2O. *American Journal of Science*, 257 (4): 241-270.

"An experimental investigation was made at elevated temperatures and pressures of the hydrolysis of K-feldspar to mica and silica and of mica to kaolinite. Values of the equilibrium quotient m_{KCl}/m_{HCl} were determined at temperatures ranging from 200 to 550°C. The solution pressure for most of the runs was 15,000 psi, although determinations were made at both higher and lower pressures." Geologic applications to hydrothermal processes and metamorphism are discussed. Suitable for graduates and advanced undergraduates. Background necessary: physical chemistry and thermodynamics.

Metz, P.W., and H.G.F. Winkler. 1963. Experimentelle Gesteinsmetamorphose - VII. Die Bildung von Talk aus kieseligem Dolomit. *Geochimica et Cosmochimica Acta*, 27 (5): 431-457.

Mixtures of dolomite, quartz, and varying amounts of water have been subjected to experimental metamorphism in the temperature range 250 to 550°C under constant total gas-pressure of 2,000 bars. The reaction leads to the formation of talc, calcite, and CO_2. The system is analyzed in detail. Suitable for graduates and advanced undergraduates. Background necessary: physical chemistry, thermodynamics, phase rule, German; the paper is in German but has an English abstract.

Miyashiro, Akiho. 1964. Oxidation and reduction in the earth's crust with special reference to the role of graphite. *Geochimica et Cosmochimica Acta*, 28 (5): 717-729.

Arguments are developed to show that the following phenomena come under the control of graphite: the apparent oxygen deficiency, relative to pure water, of normal aqueous fluid within the crust; the relationship of oxygen pressure in graphite-bearing rocks; the apparent mobility of free oxygen; and progressive metamorphism of pelitic rocks. Suitable for graduates and advanced undergraduates. Background necessary: physical chemistry and thermodynamics.

Mueller, R.F. 1964. Phase equilibria and the crystallization of chondritic meteorites. *Geochimica et Cosmochimica Acta*, 26 (2): 189-207.

"The composition of the equilibrium 'atmosphere of crystallization' of chondritic meteorites has been calculated using thermochemical data. The physical environment of the crystallization of chondrites is discussed in terms of the limits imposed by the calculations. The significance of certain crystallization textures and the stability relations of hydrocarbons are also examined." Suitable for graduates and advanced undergraduates. Background necessary: thermodynamics and phase rule.

Ringwood, A.E. 1962. Prediction and confirmation of olivine-spinel transition in Ni_2SiO_4. *Geochimica et Cosmochimica Acta*, 26 (April): 457-469.

In an earlier paper, Ringwood proposed that it is possible to predict the pressure at which a compound will transform to a denser polymorph by a study of solid solutions of the given compound with compounds possessing closer atomic packing. The method has been applied to calculate the pressures at which the olivine-spinel transition should occur in Ni_2SiO_4.

The validity of the prediction method was confirmed by a direct search for the spinel polymorph of Ni_2SiO_4 using high-pressure techniques. The same prediction method, when applied to the non-metals Si, Ge, P, and B, which display solid solubility in α-iron, suggests that they should invert to metals at high pressure. Suitable for graduates and advanced undergraduates. Background necessary: introductory thermodynamics and basic physical and crystal chemistry.

Ringwood, A.E. 1966. Chemical evolution of the terrestrial planets. *Geochimica et Cosmochimica Acta*, 30 (1): 41-104.

This paper by Ringwood is an authoritative synthesis and appraisal of the then existing knowledge and speculation of the chemical evolution of the terrestrial planets. Several hypotheses and "possible explanations" of particular phenomena are introduced. Separate sections are devoted to Earth, the Moon, Mercury, Mars, Venus, and the Galilean Satellites of Jupiter. Suitable for graduates and advanced undergraduates. Background necessary: physical chemistry and thermodynamics. Even those with insufficient background to appreciate some of the technical arguments can benefit from reading this paper.

Ringwood, A.E., and Larry Kaufman. 1962. The influence of high pressure on transformation equilibria in iron meteorites. *Geochimica et Cosmochimica Acta*, 26 (October): 999-1010.

The phase compositions and structures of iron meteorites are discussed in terms of high-pressure diagrams, using arguments which were first advanced by H.H. Uhlig. The controversy between advocates of high-pressure and low-pressure crystallization for iron meteorites is resolved. The influence of minor components, primarily phosphorus, on crystallization equilibria is also considered. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry, phase rule, introductory thermodynamics.

Roedder, E.W. 1959. Silicate melt systems. *In* L.H. Ahrens, Frank Press, K.K. Rankama, and S.K. Runcorn (editors). *Physics and chemistry of the earth*, v. 3. Pergamon Press, London: 224-297.

The experimentally determined silicate melt systems of most interest to petrologists are reviewed. The introduction includes a brief discussion of the interpretation of phase diagrams so that it is possible to read the paper without previous preparation. Fifty-nine diagrams are included. An excellent concise account. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry.

Rosenberg, P.E., D.M. Burt, and H.D. Holland. 1967. Calcite-dolomite-magnesite stability relations in solutions: The effect of ionic strength. *Geochimica et Cosmochimica Acta*, 31 (3): 391-396.

Experimental determinations between 280 and 420°C were made concerning the effect of ionic strength (0.16M to 2M aqueous $CaCl_2$-$MgCl_2$-CO_2 solutions) on the stability relations of calcite-dolomite-magnesite.

Suitable for graduates and advanced undergraduates. Background necessary: physical chemistry, thermodynamics, integral calculus.

Seki, Yotaro, and G.C. Kennedy. 1965. Muscovite and its melting relations in the system $KAlSi_3O_8$-H_2O. *Geochimica et Cosmochimica Acta*, 29 (9): 1077-1083.

The results of experimental work are presented, and points of geologic interest are discussed. These pertain to solutions given off by a cooling granitic melt. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry with some introduction to phase diagrams.

Sommerfeld, R.A. 1967. Quartz solution reaction: 400°-500°C, 1000 bars. *Journal of Geophysical Research*, 72 (16): 4253-4257.

"It is postulated that the solution species in quartz-water solutions at 1 kb changes between 400° and 500°C. This theory is tested by determining the molecularity of the solution reaction with respect to water by means of argon-water mixtures." Suitable for graduates and advanced undergraduates. Background necessary: some introduction to solution chemistry.

Tauson, L.V. 1965. Factors in the distribution of the trace elements during the crystallisation of magmas. *In* L.H. Ahrens, Frank Press, S.K. Runcorn, and H.C. Urey (editors). *Physics and chemistry of the earth*, v. 6. Pergamon Press, New York: 215-249.

The author argues that it is impossible to reduce to one or two the factors which regulate the diadochic distribution of the trace elements during the crystallization of magmas, as has been done by previous workers. The factors are divided into three groups: (1) crystal chemical properties of the elements (type of bonding, magnitude of ionic radius, the charge, etc.); (2) variations in the structure and composition of minerals; and (3) conditions of mineral crystallization (temperature, pressure, concentration ratio of the components, rate of crystallization). Factors in the formation of nondiadochic forms of occurrence of the ore elements are considered also. Suitable for graduates and advanced undergraduates. Background necessary: physical chemistry.

Taylor, S.R. 1965. The application of trace element data to problems in petrology. *In* L.H. Ahrens, Frank Press, S.K. Runcorn, and H.C. Urey (editors). *Physics and chemistry of the earth*, v. 6: Pergamon Press, New York: 133-213.

The author draws attention to the useful results to be obtained from a study of trace element determinations of good precision and accuracy. A section is devoted to the theoretical predictions of trace element behavior, followed by sections dealing with the individual elements. The emphasis has been to provide a guide to interpreting trace element data on the basis of theoretical principles, reinforced by experimental data. Specific examples of applications to geologic problems are given. The final sections deal with the use of groups of elements in specific fields of geology. The paper has an extensive reference list. Suitable for graduates and advanced undergraduates. Background necessary: some introduction to physical chemistry.

Tuttle, O.F., and N.L. Bowen. 1958. *Origin of granite in the light of experimental studies in the system $NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2-H_2O.* Geological Society of America, New York, Memoir 74: 153 p.

This book deals with the experimental determinations of phase-equilibrium relations in the system given in the title, and with the application of these results to some petrologic problems. It is a classic in its field. Suitable for graduates and advanced undergraduates. Background necessary: phase rule.

Urey, H.C. 1962. Evidence regarding the origin of the earth (Presidential address). *Geochimica et Cosmochimica Acta*, 26 (January): 1-13.

Urey's article is a broad treatment of the subject. Subheadings include: sources of evidence; properties of the solar system; properties of the planets; meteorites; evidence from the earth; and an outline of events. Suitable for intermediate- and higher-level geology students. Background necessary: basic college chemistry and physics.

Weill, D.F. 1966. Stability relations in the Al_2O_3-SiO_2 system calculated from solubilities in the Al_2O_3-SiO_2-Na_3AlF_6 system. *Geochimica et Cosmochimica Acta*, 30 (2): 223-237.

"The solubilities of andalusite, kyanite, sillimanite, mullite, tridymite and quartz are measured in

liquids of the Al_2O_3-SiO_2-Na_3AlF_6 system at 1010 and 800°C. It is shown that the Gibbs free energy of solid phases in the Al_2O_3-SiO_2 system can be simply related to the activity of silica in the liquid with which they are in equilibrium." A pressure-temperature phase-equilibrium diagram is calculated for the solid portion of the Al_2O_3-SiO_2 system which gives a triple point, andalusite-kyanite-sillimanite, at approximately 410°C, 2400 bars. "The P_{H_2O}-T equilibrium curve for the reaction muscovite + quartz ⇄ K-feldspar + sillimanite + H_2O is found to lie approximately 60-80°C below the curve for the simple breakdown of muscovite." Suitable for graduates and advanced undergraduates. Background necessary: physical chemistry and experience with phase diagrams and thermodynamics.

Winkler, H.G.F., and Hilmar von Platen. 1961. Experimentelle Gesteinsmetamorphose-V. Experimentelle anatektische Schmelzen and ihre petrogenetische Bedeutung. *Geochimica et Cosmochimica Acta*, 24 (3-4): 250-259.

The conditions of temperature and H_2O pressure whenever quartz and alkali feldspar are constituents of a rock are considered in the formation of an anatectic melt. It is pointed out (and examples are given) that anatexis always starts with the formation of an aplitic quartz-alkali feldspar melt but that the end composition after melt depends on the composition of the original metamorphosed sediment. The formation of "granitoid" and migmatic rocks by anatexis is discussed. Background necessary: basic college chemistry, phase rule, German. (Presentation is in German with an English abstract.)

Wyllie, P.J. 1963. Application of high pressure studies to the earth sciences. *In* R.J. Bradley (editor). *High pressure physics and chemistry*, v. 2. Academic Press, London: 1-89.

This is a review chapter on the physics and chemistry of high-pressure, high-temperature research applied to all facets of the earth sciences. Background necessary: third year college chemistry, physics, and geology.

Wyllie, P.J., and J.L. Haas, Jr. 1965. The system CaO-SiO_2-CO_2-H_2O: 1. Melting relationships with excess vapor at 1 kilobar pressure. *Geochimica et Cosmochimica Acta*, 29 (8): 871-892.

"Solid-liquid-vapor phase equilibria have been determined for parts of the system CaO-SiO_2-CO_2-H_2O by delineating the phase fields intersected by the composition join $CaCO_3$-$Ca(OH)_2$-(SiO_2+4.3 weight percent H_2O) at 1 kilobar pressure between 600°C and 975°C." Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry and mineralogy with some knowledge of phase diagrams.

Wyllie, P.J., and J.L. Haas, Jr. 1966. The system CaO-SiO_2-CO_2-H_2O. II -- The petrogenetic model. *Geochimica et Cosmochimica Acta*, 30 (5): 525-543.

"The experimental study was limited to the phase relationships on the vapor-saturated liquidus surface at temperatures below 950°C." Applications to carbonatites are discussed. Suitable for graduate and advanced graduate geology courses. Background necessary: basic college chemistry, mineralogy, familiarity with the petrogenetic model. (The writer assumes familiarity with the fieid; many detailed diagrams are included.)

Wyllie, P.J., and O.F. Tuttle. 1960. The system CaO-CO_2-H_2O and the origin of carbonatites. *Journal of Petrology*, 1 (1): 1-46.

The authors systematically apply phase equilibria in a three-component system at moderate temperatures and pressures to the study of a peculiar group of rocks with broad economic interest. Background necessary: fundamental knowledge of college chemistry and geology to third-year level.

APPLICATION OF CHEMICAL CONCEPTS TO LOW-TEMPERATURE GEOLOGIC SYSTEMS

Akin, G.W., and J.V. Lagerwerff. 1965. Calcium carbonate equilibria in aqueous solutions open to the air. I. The solubility of calcite in relation to ionic strength. *Geochimica et Cosmochimica Acta*, 29 (4): 343-352.

"The solubility of calcite was determined in distilled water, and in solutions containing NaCl, $NaHCO_3$ and $CaCl_2$ alone or in certain combinations, at temperatures near 25° and partial pressures of CO_2 in the range normal for the atmosphere. The effect of ionic strength on the solubility was found in close accord with Debye-Hückel theory." Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry and solution chemistry.

Akin, G.W., and J.V. Lagerwerff. 1965. Calcium carbonate equilibria in solutions open to the air. II. Enhanced solubility of $CaCO_3$ in the presence of Mg^{2+} and SO_4^{2-}. *Geochimica et Cosmochimica Acta*, 29 (4): 353-360.

From a theory, developed in this study, on the basis of Langmuir adsorption of Mg^{2+}, SO_4^{2-}, and the ions of $CaCO_3$ on a crystal surface consisting of calcite and of CaCO having a modified calcite lattice, "an equation was derived relating the activity product (Ca^{2+}) (CO_3^{2-3}) to the concentration ratios $(Mg^{2+})/(Ca^{2+})$ and $(SO_4^{2-})/(CO_3^{2-})$ at equilibrium. The equation was fitted to solubility data on the synthetic solutions. Parameters thus evaluated separately for the effect of Mg^{2+} and of SO_4^{2-} were used together in the equation to calculate solubilities in six natural waters of widely different compositions. Good agreement was obtained with measured solubilities." Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry and solution chemistry.

Anikouchine, W.A. 1967. Dissolved chemical substances in compacting marine sediments. *Journal of Geophysical Research*, 72 (2): 505-509.

"A mathematical description of the distribution of a dissolved chemical species in interstitial water of clayey marine sediments is obtained by applying the equation of the distribution of a scalar variable to a constantly accumulating column of marine sediments. An equation describing compaction, and hence interstitial water velocity, is obtained empirically from porosity data. When the space coordinates are transformed to the moving sediment-water interface, the advection term vanishes and a simple equation involving diffusion, reaction, and local change describes the distribution of chemical species dissolved in interstitial water. This equation is solved to obtain a steady-state distribution of dissolved silicate and the diffusive flux of dissolved manganese across the sediment-water interface, and agreement between theoretical predictions and empirical data is found. The validity of assumptions used in developing the mathematical model is discussed." Suitable for graduates and advanced undergraduates. Background necessary: basic chemistry and mathematics to calculus.

Bada, J.L., and S.L. Miller. 1968. Ammonium ion concentration in the primitive ocean. *Science*, 159 (3813): 423-425.

"If ion exchange on clay minerals regulated the cations in the primitive ocean as it does in the present ocean, the pH would have been 8 and the K^+ concentration 0.01M. Since NH_4^+ and K^+ are similar in their clay-mineral equilibria, the maximum NH_4^+ concentration in the primitive ocean would also have been 0.01M. An estimate of the minimum NH_4^+ concentration is 1×10^{-3}M, based on reversible deamination of aspartic acid and the assumption that aspartic acid is necessary for the origin of life. The rate of this nonenzymic deamination is rapid on the geological time scale." Suitable for graduates and advanced undergraduates. Background necessary: ion exchange in clay minerals and basic college inorganic and organic chemistry.

Barnes, Ivan, and William Back. 1964. Dolomite solubility in ground water. U.S. Geological Survey Professional Paper 475-D [Article 160 *in* Short Papers in Geology and Hydrology]: D179-D180.

"The ion-activity product $(IAP)_d$ of dolomite has been computed for 87 samples of ground water from a variety of geologic environments. The upper limit of the $(IAP)_d$ for samples in or very near equilibrium with calcite agrees with the higher equilibrium constants reported in the literature." Suitable for graduates and advanced undergraduates. Background necessary: introduction to solution chemistry.

Bender, M.L., Teh-Lung Ku, and W.S. Broecker. 1966. Manganese nodules: Their evolution: *Science*, 151 (3708): 325-328.

This paper is a short, well-written review of the problem of marine manganese nodule formation. The authors deal with the trace-element geochemistry of the nodules, their rate and mode of formation, and their distribution in the oceans. It is written at an introductory geology level and would require only a basic knowledge of chemistry.

Berner, R.A. 1963. Electrode studies of hydrogen sulfide in marine sediments. *Geochimica et Cosmochimica Acta*, 27 (6): 563-575.

"An electrode has been prepared and applied to the measurement and detection of hydrogen sulfide in natural sediments and in laboratory experiments. When properly calibrated, the silver-silver sulfide electrode used in conjunction with platinum and glass electrodes can be used to determine equilibrium activities of dissolved sulfide and polysulfide species, as well as the partial pressure of H_2S...The process of H_2S formation by sulfate-reducing bacteria can be followed with the electrode. Through use of the platinum and silver-silver sulfide electrodes it has been discovered that the Eh of many sediments

containing H_2S is controlled by the reversible half-cell:

$$HS^-_{aq.} \rightleftarrows S^\circ_{rhmb.} + H^+_{aq.} + 2e$$

which is equivalent to the half cell:

$$S^{2-}_{aq.} \rightleftarrows S^\circ_{rhmb.} + 2e."$$

Suitable for graduates and advanced undergraduates. Background necessary: basic solution chemistry and electrochemistry.

Berner, R.A. 1964. An idealized model of dissolved sulfate distribution in recent sediments. *Geochimica et Cosmochimica Acta*, 28 (9): 1497-1503.

"The processes considered by the model are ionic diffusion, deposition plus compaction, and bacterial sulfate reduction. Rate parameters (diffusion coefficient, rate of bacterial sulfate reduction) calculated from the model, for a sediment core from the Santa Barbara Basin of southern California, agree within an order of magnitude with values estimated by independent methods." Suitable for graduates and advanced undergraduates. Background necessary: calculus and basic college physical chemistry.

Berner, R.A. 1965. Activity coefficients of bicarbonate, carbonate and calcium ions in sea water. *Geochimica et Cosmochimica Acta*, 29 (8): 947-965.

"Measurements of pH of sea water samples equilibrated with known partial pressures of CO_2 and with calcite and aragonite have enabled the determination of molal activity coefficient of bicarbonate, carbonate, and calcium ions in two sea water samples at 25°C and 1 atm total pressure." Comparison of the ion activity product (IAP = $a_{Ca^{2+}} \cdot a_{CO_3^{2-}}$) with the thermodynamic solubility product, K_s, of calcite and aragonite indicates that low latitude surface sea water is supersaturated with respect to both phases, whereas a large proportion of subsurface sea water is undersaturated with respect to all forms of $CaCO_3$. Suitable for graduates and advanced undergraduates. Background necessary: physical chemistry.

Berner, R.A. 1968. Rate of concretion growth. *Geochimica et Cosmochimica Acta*, 32 (5): 477-483.

"Mathematical expressions for the time of growth of spherical post-depositional concretions from flowing and non-flowing supersaturated ground water are derived based on ionic diffusion as the rate-controlling growth mechanism. Application of the equations to the growth of $CaCO_3$ concretions is done in the form of growth curves for different ground water flow rates." Suitable for graduates and advanced undergraduates. Background necessary: mathematics to integral calculus.

Bischoff, J.L., and W.S. Fyfe. 1968. Catalysis, inhibition, and the calcite-aragonite problem: 1. The aragonite-calcite transformation: *American Journal of Science*, 266 (2): 65-79.

This is an excellent review of field, experimental, and theoretical observations on the transition of aragonite to calcite and hence on the origin of calcium carbonate muds. Emphasis is on experimental results and their application to natural systems. The article is well-written but is at an intermediate to advanced level. Some background calculus and physical chemistry on the part of the reader would be advised.

Bredehoeft, J.D., C.R. Blyth, W.A. White, and G.B. Maxey. 1963. Possible mechanism for concentration of brines in subsurface formations. *American Association of Petroleum Geologists Bulletin*, 47 (2): 257-269.

A mechanism is suggested for the development of brines in subsurface formations. The mathematical model presented predicts the distribution of ions within a particular formation under ideal conditions. The theoretical concentrations from the model are shown to have a striking similarity to observed concentrations. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry and mathematics to integral calculus.

Bricker, O.P. 1965. Some stability relations in the system $Mn-O_2-H_2O$ at 25° and one atmosphere total pressure. *American Mineralogist*, 50 (9): 1296-1354.

"Stability relations in the system $Mn-O_2-H_2O$ were investigated at 25°C and one atmosphere total pressure. Seven compounds, $Mn(OH)_2$, Mn_3O_4, γMn_2O_3, γ-MnOOH, δ-MnO_2, γ-MnO_2 and hydrohausmannite, were synthesized under controlled conditions of Eh and pH...Free energy of formation data were obtained for

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the first six compounds listed...A model is described for the supergene oxidation of rhodochrosite." Suitable for graduates and advanced undergraduates. Background necessary: physical chemistry, thermodynamics, mineral water equilibria.

Campbell, A.S., and W.S. Fyfe. 1965. Analcime-albite equilibria. *American Journal of Science*, 263 (9): 807-816.

"New data are presented that suggest the reaction:

analcime + quartz = albite + liquid water

is in equilibrium near 190°C or possibly at even lower temperatures." A phase diagram is constructed. The ΔG° is estimated. Factors that may influence equilibria, such as salinity, silica activity, solid solutions, and order-disorder, are considered. "Experimental difficulties associated with studies of zeolite equilibria are considered in the light of entropy data." Suitable for graduates and advanced undergraduates. Background necessary: phase rule and introductory thermodynamics.

Carr, R.M. 1963. Synthesis fields of some aluminum silicates--Further studies. *Geochimica et Cosmochimica Acta*, 27 (2): 133-135.

It is shown "that the P-T field in which a phase or assemblage of phases may be synthesized need not be identical with that in which it is stable, but also illustrates the importance of choice of experimental method for those laboratory studies designed to clarify petrological data." Pyrophyllite, x-andalusite, silica-kaolinite, quartz-kaolinite field-size changes with changes in experimental methods are treated. "Synthesis studies in the system Al_2O_3--(6-8)SiO_2--0.05 K_2O indicate catalysis of the nucleation of x-andalusite." Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry and phase rule.

Chave, K.E. 1960. Evidence on history of sea water from chemistry of deeper subsurface waters of ancient basins. *American Association of Petroleum Geologists Bulletin*, 44 (3): 357-370.

On the assumption that subsurface waters in ancient basins are remnants of sea water entrapped with sediments at the time of their deposition, the possibility of using their chemical composition as an indicator of ancient sea water chemistry is investigated. Postdepositional processes altering the water chemistry are discussed. It is concluded that the magnitude of the modifying processes is large. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry.

Christ, C.L., A.H. Truesdell, and R.C. Erd. 1967. Borate mineral assemblages in the system Na_2O-CaO-MgO-B_2O_3-H_2O. *Geochimica et Cosmochimica Acta*, 31 (3): 313-337.

This is a methodical presentation of the relations of the natural phases of the system Na_2O-CaO-MgO-B_2O_3-H_2O. By using data from the literature, by field observations, and by examining available mineral specimens, it was found that the significant hydrated borate mineral assemblages could be represented conveniently by three ternary composition diagrams. The discussion is confined to evaporite hydrated borates and their low-grade metamorphic products, which nevertheless constitute the most important borates geologically and economically. Particular attention is paid to the borate deposits of the western United States, but the deposits of other countries are considered briefly. Within the limits of the discussion, there emerges a very reasonable physical-chemical picture of the observed assemblages. Suitable for graduates and advanced undergraduates. Background necessary: crystal chemistry, physical chemistry, thermodynamics, phase rule.

Cloke, P.L. 1963. The geologic role of polysulfides--Part II. The solubility of acanthite and covellite in sodium polysulfide solutions. *Geochimica et Cosmochimica Acta*, 27 (12): 1299-1319.

"The solubility of synthetic low-temperature silver sulfide (acanthite) in solutions of sodium polysulfide of different concentrations, different ratios of sulfur to sulfide, and different acidity was determined." Using the previously published activities of polysulfide ions it was possible to calculate three complexes of silver ion and analogous complexes of copper ion. "Application of this study to ore deposition depends on somewhat uncertain extrapolations to higher temperatures and pressures." Deposition is considered from the points of view of the size of the stability field of polysulfides at elevated temperature and pressure; variations in pH; oxidations and reduction; and reaction with ferrous minerals. Suitable for graduates and advanced undergraduates. Background necessary: solution chemistry and familiarity with Eh-pH diagrams.

Cloud, P.E., Jr. 1962. Behaviour of calcium carbonate in sea water. *Geochimica et Cosmochimica Acta*, 26 (8): 867-884.

Solubility product constants for aragonite and calcite are determined. Field data and experimental results indicate that the mineralogy of precipitated $CaCO_3$ depends primarily on degree of supersaturation. Conditions influencing supersaturation and aragonite to calcite conversions are discussed. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry including some solution chemistry.

Cox, R.A., Fred Culkin, R. Greenhalgh, and J.P. Riley. 1962. Chlorinity, conductivity and density of sea-water. *Nature*, 193 (4815): 518-520.

A progress report of some 200 analyses of a larger collection of sea-water samples with worldwide distribution. The results show that the ionic composition of sea water is not constant but that there are significant variations in chemical constitution from place to place and surface to bottom. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry.

Culberson, Charles, D.R. Kester, and R.M. Pytkowicz. 1967. High-pressure dissociation of carbonic and boric acids in seawater. *Science*, 157 (3784): 59-61.

"The apparent dissociation constants of carbonic and boric acids were determined for pressures up to 654 atmospheres in seawater of 34.6 per mille salinity at 22°C." Suitable for graduates and advanced undergraduates. Background necessary: physical chemistry.

Ellis, A.J. 1959. The system Na_2CO_3-$NaHCO_3$-CO_2-H_2O at temperatures up to 200°. *American Journal of Science*, 257 (4): 287-296.

"The equilibrium conditions in the system above were obtained by a differential vapor pressure method and the results up to 200° are reported...The vapor pressures of sodium chloride and sodium carbonate solutions up to 200° are given, but it was not possible to obtain results of sufficient accuracy to derive activity coefficients."

Frederickson, A.F., and R.C. Reynolds, Jr. 1960. Geochemical method for determining paleosalinity. *In* Ada Swineford (editor). *Clays and clay minerals*. [Proceedings of the Eighth National Conference on Clays and Clay Minerals]. Pergamon Press, New York, International Earth Science Series Monograph 9: 203-213.

It is proposed that the boron content of illite minerals in sedimentary rocks can be used to evaluate the salinity of the sea prevailing at the time the sediment was deposited. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry and clay mineralogy.

Galliher, E.W. 1933. The sulfur cycle in sediments. *Journal of Sedimentary Petrology*, 3 (2): 51-63.

"The origin and transformation of sulfur in sediments is considered from the geobiological point of view. The general sulfur cycle is outlined, and the part some of the organisms may play in the formation of petroleum is suggested. The relation between the quantity of organic matter and ferrous sulphide in a sediment is shown." Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry.

Garrels, R.M., and C.L. Christ. 1965. *Solutions, minerals, and equilibria*. Harper & Row, New York: 450 p.

This book is a classic reference to thermodynamics applied to low-temperature geologic systems. It provides an excellent discussion of activity-concentration relations, carbonate equilibria, complex ions, partial-pressure diagrams, and Eh-pH diagrams. Emphasis is on computation and display of equilibrium relationships in mineral systems. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry.

Garrels, R.M., and M.E. Thompson. 1962. A chemical model for sea water at 25°C and one atmosphere total pressure. *American Journal of Science*, 260 (1): 57-66.

"Dissociation constants involving Ca^{++}, Mg^{++}, Na^{+}, K^{+}, SO_4^{--}, HCO_3^{-} and CO_3^{--} ions, and individual ion activity coefficients have been used to calculate the distribution of dissolved species in sea water at 25°C and one atmosphere total pressure." The distribution was determined for sea water of chlorinity 19‰ and pH 8.1. The cations Ca, Mg, Na, K were determined in terms of % free ion, % Me-SO_4, % Me-HCO_3, and % Me-CO_3; likewise, the three anions were determined in terms of % free ion, % Ca-anion, % Na-anion, % Mg-anion and % K-anion. Suitable for graduates and advanced undergraduates. Background necessary: basic chemistry with some knowledge of solution chemistry.

Goldberg, E.D. 1958. The processes regulating the composition of sea water. *Journal of Chemical Education*, 35 (3): 116-119.

This is a well-written short article emphasizing the inorganic and biochemical processes regulating sea-water composition. The author considers the balance sheet of ocean chemistry from those processes contributing ions to those removing them. Also discussed is the constancy of composition of the oceans. This article can be easily understood by the beginning geology student.

Gorham, Eville, and D.J. Swaine. 1965. The influence of oxidizing and reducing conditions upon the distribution of some elements in lake sediments. *Limnology and Oceanography*, 10 (2): 268-279.

"Analyses for Fe, Mn, Pb, Zn, Co, P, Mo, Ba, Sr, Ti, Li, Rb, Na, K, Be, Cr, V, Y, Ag, Cu, C, S, Sn, Ni, Ga, Zr, and La have been carried out on some oxidate crusts, oxidized surface muds, reduced subsurface muds and glacial clays" in two English lakes. "Relations between the elements in the various sediments are examined, and the English oxidate crusts are compared with lake and stream ores in Sweden and Finland, and with marine manganese nodules." Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry.

Graf, D.L. 1960. Geochemistry of carbonate sediments and sedimentary carbonate rocks. *Illinois State Geological Survey Division.*

Part I. Carbonate mineralogy and carbonate sediments. Circular 297: 39 p.
Part II. Sedimentary carbonate rocks. Circular 298: 43 p.
Part III. Minor element distribution. Circular 301: 71 p.
Part IVa. Isotopic composition and chemical analyses. Circular 308: 42 p.
Part IVb. Bibliography. Circular 309: 55 p.

The author presents a selective treatment of the geochemistry of carbonate sediments and carbonate rocks, surprisingly complete in its scope. Titles of the four parts, distributed as separate circulars, indicate the subject matter. Together, they provide an invaluable collection of data with good discussions. Background necessary: general college chemistry. The papers are clear and well-written and serve as a good introduction to this broad field.

Green, E.J., and D.E. Carritt. 1967. Oxygen solubility in sea water: Thermodynamic influence of sea salt. *Science*, 157 (3785): 191-193.

"Precise measurements of the solubility of oxygen in sea water show that the solubility declines exponentially with increase in salt concentration according to the empirical Setschenow relation. The deviation from linearity is nearly 0.6 percent from the fitted straight-line relations of previous workers." The experimental data presented here show that salting-out decreases with increasing temperature which is in contrast to the effect predicted by the Debye theory. Suitable for graduates and advanced undergraduates. Background necessary: physical chemistry and thermodynamics.

Halevy, E. 1964. The exchangeability of hydroxyl groups in kaolinite. *Geochimica et Cosmochimica Acta*, 28 (7): 1139-1145.

"HTO and H_2O^{18} were used to investigate the isotopic exchange of hydroxyl groups in kaolinite. The per cent exchange of surface hydroxyls were found to be small (<1%), but enough to account for a possible mechanism of anion exchange of a few milliequivalents per 100 g." Suitable for graduates and advanced undergraduates. Background necessary: clay mineralogy including some introduction to ion exchange.

Hanshaw, B.B. 1963. Preliminary relations in the system $Na_2B_4O_7$-$Ca_2B_6O_{11}$-H_2O. U.S. Geological Survey Professional Paper 475-B [Article 7 *in* Short Papers in Geology and Hydrology]: B24-B27.

A semiquantitative phase diagram constructed by using the symmetry of the equilibrium constants and the recorded phases coexisting naturally in presumed equilibrium is presented. New relations among the sodium borates are suggested, and experimental methods for studying the three-component system are outlined. Suitable for graduates and advanced undergraduates. Background necessary: basic chemistry and phase rule.

Hardie, L.A. 1967. The gypsum-anhydrite equilibrium at one atmosphere pressure. *American Mineralogist*, 52 (1 and 2): 171-200.

The author presents a clear, revealing, and excellent study of the solubility and phase equilibrium in the system Ca-SO_4-H_2O. Reversible equilibrium is achieved between gypsum and anhydrite. The equilibrium between these two important sedimentary minerals is expressed as a function of temperature and the activity

of water. This article demonstrates how salinity and temperature of natural waters control the precipitation of gypsum and anhydrite in nature. Advanced treatment. Background necessary: physical chemistry.

Harriss, R.C. 1967. Clay minerals and oceanic evolution. *In* S.W. Bailey (editor). *Proceedings of the fifteenth national conference on clays and clay minerals*. Pergamon Press, New York: 207-214.

The ocean is apparently undersaturated with respect to equilibrium silica concentrations for all the clays except kaolinite. Thus, the author proposes that the present lack of any geologic evidence in support of the equilibrium hypotheses indicates that alternative hypotheses for compositional control of ocean chemistry should be considered. The approach used is to consider, using the available geologic observations as a framework, the relative importance of clay mineral reactions with coexisting natural waters in the terrestrial weathering environment, marine environment, and subsurface environment in the chemical evolution of alkali metals in ocean water. Suitable for graduates and advanced undergraduates. Background necessary: clay mineralogy and basic college chemistry.

Hayes, F.R. 1964. The mud-water interface. *In* Harold Barnes (editor). *Oceanography and marine biology annual review*, v. 2. Hafner Publishing Company, New York: 121-145.

This is a review dealing with the exchanges between the water and the products that reach the bottom to constitute sediments. Attention is mostly restricted to what might be called general conditions where there is a relatively undisturbed fallout with some organic component away from shore in lakes and bays. Headings and subheadings include: components of the mud -- organic and inorganic; processes in the mud -- adsorption (especially of phosphate), oxidation-reduction effects, reactions of sulfur, and the intervention of bacteria; exchange between mud and water -- oxygen uptake, liberation of nutrients under reducing conditions, and measurements with radioactive phosphorus. Suitable for graduates and intermediate and advanced undergraduates. Background necessary: basic organic and inorganic chemistry.

Helz, G.R., and H.D. Holland. 1965. The solubility and geologic occurrence of strontianite. *Geochimica et Cosmochimica Acta*, 29 (12): 1303-1315.

"The solubility of natural strontianite has been measured at 50, 100, and 200°C in aqueous solutions in equilibrium with a vapor phase containing CO_2 at pressures between 1 and 50 atm." The precipitation of strontianite in geologic settings is discussed in terms of the experimental results. Suitable for graduates and advanced undergraduates. Background necessary: physical chemistry with some introduction to thermodynamics.

Hess, P.C. 1966. Phase equilibria of some minerals in the K_2O-Na_2O-Al_2O_3-SiO_2-H_2O system at 25°C and 1 atmosphere. *American Journal of Science*, 264 (4): 289-309.

Phase equilibria in the system are "depicted graphically in terms of the parameters log K^+/H^+, log Na^+/H^+ and log SiO_2 at 25°C and 1 atmosphere." Data on naturally occurring mineral assemblages and on the chemistry of the coexisting aqueous phase and previously published laboratory investigations are used to construct the phase diagram. "The results show that K-mica, K-feldspar, montmorillonite and phillipsite are all stable in an environment chemically equivalent to that existing in oceanic sediments. The kaolinite field is favored by lower alkali/H^+ ratios while gibbsite is restricted to systems that contain extremely low silica values, probably less than 1 ppm. Albite and analcite are indicative of high log Na^+/H^+ concentrations." Suitable for graduates and advanced undergraduates. Background necessary: solution chemistry and phase rule.

Holland, H.D., Maria Borcsik, J.L. Munoz, and U.M. Oxburgh. 1963. The coprecipitation of Sr^{+2} with aragonite and of Ca^{+2} with strontianite between 90° and 100°C. *Geochimica et Cosmochimica Acta*, 27 (9): 957-977.

In experiments, aragonite and/or strontianite were precipitated from aqueous solutions between 90-100°C by carbonate ions generated during hydrolysis of trichloroacetate ions. "It was found that surface equilibrium is maintained between solution and precipitate during the precipitation process and that the distribution of strontium and calcium between solution and precipitate obeys the Doerner-Hoskins equation." Changes in the distribution coefficient k^A_{Sr} and the unit cell dimensions of the solid solution (Ca, Sr) CO_3 were documented and discussed. Geologic applications are discussed. Suitable for graduates and advanced undergraduates. Background necessary: basic solution and crystal chemistry.

Holland, H.D., H.J. Holland, and J.L. Munoz. 1964. The coprecipitation of cations with $CaCO_3$ --II. The coprecipitation of Sr^{+2} with calcite between 90 and 100°C. *Geochimica et Cosmochimica Acta*, 28 (8): 1287-1301.

The distribution coefficient of Sr^{+2} between solution and calcite k^{c}_{Sr} was obtained with precision, and that of Sr^{+2} between solution and aragonite k^{a}_{Sr} approximately. The value of k^{c}_{Sr} is independent of the ionic strength of the solution up to 1.4 m, of the mole fraction of Sr^{+2} in solution, and probably nearly independent of the NaCl concentration in the solution from which it is precipitated. The value of k^{c}_{Sr} reported can therefore be used to define the ratio $(M_{Sr}{}^{+2}/M_{Ca}{}^{+2})$ in hydrothermal solutions from which calcite has been deposited at 100°C. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry with solution chemistry.

Huber, N.K. 1958. The environmental control of sedimentary iron minerals. *Economic Geology*, 53 (2): 123-140.

The author develops the relationship of common iron minerals to such environmental variables as Eh, pH, SO_4^{2-}, CO_3^{2-} and ionic activity. Background necessary: basic college chemistry.

Kanwisher, J. 1961. PCO_2 in sea water and its effect on the movement of CO_2 in nature. *Tellus*, 12 (2): 209-215.

A method is described for measuring pCO_2 in sea water. A gas phase is analyzed continuously by infrared absorption for CO_2 while it is equilibrated gently with water in a countercurrent column. It has been used to determine the changes in pCO_2 produced by variations of temperature and total CO_2. Partial pressure shows large changes for small increments in these two independent variables. These properties of sea water are useful in estimating the movement of CO_2 between the atmosphere and oceans. It appears, for instance, that most of the fossil fuel CO_2 released by man has been effective in increasing the percentage of this gas in air. Suitable for graduates and advanced undergraduates. Background necessary: basic chemistry and some introduction to solution chemistry.

James, H.L. 1954. Sedimentary facies of iron-formation. *Economic Geology*, 49 (3): 235-293.

This paper is a classic application of Eh-pH conditions to the concept of sedimentary facies. The iron-formations can be divided on the basis of the original dominant iron mineral into four principal facies: sulfide, carbonate, oxide, and silicate. Distribution of iron formations is related to the environment of deposition. Background necessary: basic college chemistry.

Kaplan, I.R., K.O. Emery, and S.C. Rittenberg. 1963. The distribution and isotopic abundance of sulphur in recent marine sediments off southern California. *Geochimica et Cosmochimica Acta*, 27 (4): 297-331.

"Analyses of sulphur compounds in basin sediments off southern California indicate that elemental sulphur, free sulphide, hydrotroilite, organic sulphur, sulphate and pyrite are present in quantities that vary with environment and depth in the sediments." Isotope measurements confirm many of the conclusions suggested by the quantitative chemical analyses. "They show that biological sulphate reduction is the single most important process in the sulphur cycle...Data from field and laboratory experiments were combined to determine rate of sulphate reduction, number of sulphate reducing bacteria and the amount of organic matter decomposed during sulphate reduction in the sediment, as well as rate of renewal of water in the basins." Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry and some introduction to stable isotopes.

Keller, W.D. 1962. *The principles of chemical weathering* (New Edition). Lucas Brothers Publishers, Columbia, Missouri: 111 p.

This book is an outstanding, clearly written, and stimulating treatment of the fundamental processes of chemical weathering and provides good insight into the general and specific aspects of the chemical weathering of rocks and minerals. There is no better treatment available on this introductory level. Background necessary: basic college chemistry.

Kester, D.R., and R.M. Pytkowicz. 1968. Magnesium sulfate association at 25C in synthetic seawater. *Limnology and Oceanography*, 13 (4): 670-674.

A value for the stoichiometric association constant $[K^{*}MgSO_4]$ was obtained and used to make a preliminary estimate of the sulfate speciation in seawater. Suitable for graduates and undergraduates. Background necessary: some introduction to solution chemistry.

Kitano, Yasushi, and D.W. Hood. 1965. The influence of organic material on the polymorphic crystallization of calcium carbonate. *Geochimica et Cosmochimica Acta*, 29 (1): 29-41.

Experiments indicate the chemical precipitation of calcium carbonate from bicarbonate solutions into its polymorphic forms calcite, aragonite, and vaterite is greatly influenced by the presence of different organic compounds. For example, compounds of citrate, malate, pyruvate, glycylglycine, and glycogen greatly reduce the rate of carbonate precipitation and favor formation of the stable form of calcite. Other compounds affect the rate to a moderate degree and have mixed effects on the crystal form resulting. Suitable for graduates and advanced undergraduates. Background necessary: solution chemistry and basic college organic chemistry.

Kittrick, J.A. 1966. The free energy of formation of gibbsite and $Al(OH)_4^-$ from solubility measurements. *Soil Science Society of America Proceedings*, 30 (5): 595-598.

"The value for gibbsite confirms previous work on the stability of gibbsite and the new $Al(OH)_4^-$ value eliminates a discrepancy between gibbsite stabilities derived from solubility measurements in the acid and in the alkaline pH range." Suitable for graduates and advanced undergraduates. Background necessary: solution chemistry and thermodynamics.

Kittrick, J.A. 1967. Gibbsite-kaolinite equilibria. *Soil Science Society of America Proceedings*, 31 (3): 314-316.

"In order to help determine if the equilibria reached by soil mineral mixtures is that predicted on the basis of single minerals, two kaolinite samples were equilibrated individually and also with gibbsite of known stability. One set of samples was equilibrated from undersaturation, the other from supersaturation. Samples were analyzed periodically and equilibrium values obtained by extrapolation to infinite time. The solution ion compositions found were those predicted on the basis of the solubilities of the individual minerals." Suitable for graduates and advanced undergraduates. Background necessary: solution mineral equilibria and introductory thermodynamics.

Kramer, J.R. 1965. History of sea water. Constant temperature-pressure equilibrium models compared to liquid inclusion analyses. *Geochimica et Cosmochimica Acta*, 29 (8): 921-945.

A theoretical inorganic ocean is derived from the solution equilibrium of clay minerals, calcite, OH-apatite, CO_3-F-apatite, phillipsite, gypsum, strontianite, celestite, and aragonite. "The minerals are considered in equilibrium in different combinations with and without chloride." A "most probable" model for the major ions has concentrations very close to sea water. "Upper limit" and "lower limit" models are considered. "Liquid inclusion analyses from salt and chert from the Silurian Salina and Niagaran Groups of Michigan, Ontario, Ohio, and Wisconsin compare very favorably with modern ocean compositions except that Ca and Mg compositions appear to be reversed." Such inclusions are assumed (with some precautions) to be sea water. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry and mathematics to calculus. This article is a logical presentation and contains a good reference list.

Kramer, J.R. 1969. Mineral-water equilibria in silicate weathering. *In* Jan Kantor (editor). *XXIII International Geological Congress Proceedings, Section 6, Geochemistry* [Prague, Czechoslovakia, 1968]: 149-160.

This study summarizes the thermodynamic data now available, includes some new thermodynamic data on illite and Mg-chlorite, and compares theoretical conclusions from these data to field analyses of waters in a Precambrian "granite" terrane, a Precambrian sedimentary terrane, and a Paleozoic limestone terrane. Suitable for graduates and advanced undergraduates. Background necessary: thermodynamics, phase rule, solution chemistry.

Lerman, Abraham. 1967. Model of chemical evolution of a chloride lake -- the Dead Sea. *Geochimica et Cosmochimica Acta*, 31 (12): 2309-2330.

The Dead Sea brines are unique insofar as their concentration of sulfate and carbonate is very low (the main ion being chloride), and insofar as they lack any appreciable complexing of the chloride ion by Na^+, K^+, Ca^{2+}, and Mg^{2+} at temperatures below 100°C (references are cited). These qualities prompted Lerman to attempt to describe the brines and sediments of the Dead Sea in terms of the chemical behavior of ions present in solution. This is possibly the first attempt to treat the geochemistry of natural chloride brines in terms of the theories of concentrated solutions of highly soluble mineral phases. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry and some knowledge of solution chemistry.

Lovering, T.G., and L.E. Patten. 1962. The effect of CO_2 at low temperature and pressure on solutions supersaturated with silica in the presence of limestone and dolomite. *Geochimica et Cosmochimica Acta*, 26 (July): 787-796.

"The effect of 1 atm of CO_2 over initially neutral solutions supersaturated with silica, at room temperature, as contrasted with 1 atm of air was determined over a period of 5 months, together with changes brought about by the introduction of calcite and dolomite to these solutions in the form of either chips or finely ground powder." Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry including some solution chemistry.

Lynn, D.C., and Enrico Bonatti. 1965. Mobility of manganese in diagenesis of deep-sea sediments. *Marine Geology*, 3 (6): 457-474.

"A relatively high content of manganese has been found at the top of several deep-sea sediment cores from the Pacific. The sediments underlying these manganese-rich layers show evidence of reducing conditions. The data suggest that manganese dissolves upon burial in reduced sediments, then slowly migrates and accumulates in the oxidized top strata. Ionic or molecular diffusion in the pore solution appears to be the main mechanism by which such migration takes place...Some geochemical implications of the redistribution of manganese and associated elements in deep-sea sediments are briefly discussed." Suitable for graduates and advanced undergraduates. Background necessary: solution equilibria of minerals and basic chemistry.

Mackenzie, F.T., and R.M. Garrels. 1965. Silicates: Reactivity with sea water. *Science*, 150 (3692): 57-58.

Experiments with kaolinite, chlorite, illite, muscovite, and montmorillonite show that these silicate minerals rapidly release silica to sea water. "The rates observed indicate that the ocean must be looked upon as a chemical system with a rapid response to added detrital silicates." Suitable for graduates and advanced undergraduates. Background necessary: basic chemistry.

Mackenzie, F.T., and R.M. Garrels. 1966. Chemical mass balance between rivers and oceans. *American Journal of Science*, 264 (7): 507-525.

The stated purpose of this paper is to present a simple chemical mass balance between streams and oceans. This mass balance is an attempt to evaluate the processes that lead to the removal of stream-derived dissolved constituents from the ocean system and to see what reactions are necessary to accomplish this removal and to maintain present ocean water composition. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry.

Mackenzie, F.T., and R.M. Garrels. 1966. Silica-bicarbonate balance in the ocean and early diagenesis. *Journal of Sedimentary Petrology*, 36 (4): 1075-1084.

The authors present an intermediate-level discussion of the important problem of removing from the sea the large quantity of dissolved silica and bicarbonate added perennially by rivers. The article shows how the volumes of chert and carbonate sediment in the geologic record are insufficient to account for the quantity of silica and bicarbonate added. It is suggested that the silica is incorporated in reconstituted layer silicates during early diagenesis, with the bicarbonate being converted to carbon dioxide gas and lost to the atmosphere. Background necessary: basic college chemistry. This is a paper of fundamental importance; the presentation is clear and straightforward.

McConnell, Duncan. 1965. Precipitation of phosphates in sea water. *Economic Geology*, 60 (5): 1059-1062.

"The principles of inorganic chemistry seem to be inadequate to account for phosphorites; various sorts of possible biochemical influences are suggested." Suitable for graduates and advanced undergraduates. Background necessary: basic inorganic and organic chemistry.

McKinnell, J.C. 1958. Identification of mixtures of waters from chemical water analyses. *Petroleum Transactions, American Institute of Mechanical Engineers*, 213: 402-405.

Identifying complex mixtures of waters presents many problems that can be solved by graphic methods described in this paper. Examples are presented to show the application of these methods to the correlation of oil-field waters and the determination of the percentage of each water in mixtures of two and three waters. Suitable for graduates and advanced undergraduates. Background necessary: geometry and basic college chemistry.

McNamara, M.J. 1966. Chlorite-biotite equilibrium reactions in a carbonate-free system. *Journal of Petrology*, 7 (3): 404-413.

Mineral phase stability of biotite and chlorite, K-feldspar and muscovite on a $[K^+]/[H^+]$-temperature diagram is discussed. The diagram is applied to suggest a sequence of assemblages denoting metamorphic grade. Suitable for graduates and advanced undergraduates. Background necessary: phase rule and basic college chemistry.

Ostroff, A.G. 1964. Conversion of gypsum to anhydrite in aqueous salt solutions. *Geochimica et Cosmochimica Acta*, 28 (9): 1363-1372.

Thermodynamic calculations and experimental evidence substantiate that the reaction mechanism (at 90.5°C) is the conversion of gypsum first to the hemihydrate and then to natural anhydrite. Suitable for graduates and advanced undergraduates. Background necessary: basic physical chemistry and thermodynamics.

Platford, R.F., and Thomas Dafoe. 1965. The activity coefficient of sodium sulfate in seawater. *Journal of Marine Research*, 23 (2): 63-68.

"The mean activity coefficient of sodium sulfate in artificial seawater has been measured with a sodium amalgam electrode and a lead amalgam-lead sulfate electrode." Data suggest that a considerable fraction of the sulfate ion is tied up as a sodium sulfate complex. Suitable for graduates and advanced undergraduates. Background necessary: some introduction to solution chemistry.

Posselt, H.S., A.H. Reidies, and W.J. Weber, Jr. 1968. Coagulation of colloidal hydrous manganese dioxide. *Journal of the American Water Works Association*, 60 (1): 48-68.

This article explores in some detail factors governing the destabilization and precipitation of colloidal hydrous manganese dioxide in water-treatment practice, with particular emphasis on evaluation of appropriate coagulation controls that might permit more effective removal of this material from water supplies. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry with some introduction to colloid chemistry.

Pytkowicz, R.M. 1967. Carbonate cycle and the buffer mechanism of recent oceans. *Geochimica et Cosmochimica Acta*, 31 (1): 63-73.

"Existing estimates of the fluxes of carbon dioxide and carbonates through the oceans are extended to include solution of calcium carbonate and oxidative regeneration of carbon dioxide at depth. The relative roles of carbonates and silicates in the buffer mechanism of the oceans are examined and it is shown that, within a short time scale, carbonates are the primary buffering agents." Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry. This paper is clearly written with a good diagram of the carbonate and carbon dioxide cycles in recent oceans.

Pytkowicz, R.M., I.W. Duedall, and D.N. Connors. 1966. Magnesium ions: Activity in sea water. *Science*, 152 (3722): 640-642.

The activity of magnesium ions in seawater was determined from solubility data and found to be between previously published values. The value obtained may result from extensive formation of magnesium sulfate ion pairs. Suitable for graduates and advanced undergraduates. Background necessary: some introduction to solution chemistry.

Pytkowicz, R.M., and R. Gates. 1968. Magnesium sulfate interactions in seawater from solubility measurements. *Science*, 161 (3842): 690-691.

"The extent of association between magnesium and sulfate ions was determined in artificial seawater by a solubility technique. About 10 percent of the magnesium ions were found to be associated." This result supersedes an earlier value obtained by the authors and agrees with the results of Garrels and Thompson, Thompson, and Fisher. Suitable for graduates and advanced undergraduates. Background necessary: some introduction to solution chemistry.

Pytkowicz, R.M., and D.R. Kester. 1969. Harned's rule behavior of $NaCl$-Na_2SO_4 solutions explained by an ion association model. *American Journal of Science*, 267 (2): 217-229.

This paper reports the measurements and the interpretation of short-range interactions between sodium and sulfate ions at ionic strengths between 0.3 and 1.0 at 25°C. The results show that a modified expression of Harned's rule, derived from the "association model," provided a better description of the behavior of the sodium chloride activity coefficient in $NaCl$-Na_2SO_4 solutions than that provided by the usual form of Harned's rule. Suitable for graduates and advanced undergraduates. Background necessary: some introduction to solution chemistry.

Reesman, A.L., and W.D. Keller. 1968. Aqueous solubility studies of high-alumina and clay minerals. *American Mineralogist*, 53 (5 and 6): 929-942.

"Solubility constants and standard free energies of formation for various high-alumina minerals and clay minerals were calculated from data on concentrations of ions dissolved in aqueous solution from those minerals." The minerals are dickite, kaolinite, "fire-clay mineral," halloysite, endellite, montmorillonite, gibbsite, boehmite, diaspore, pyrophyllite, and muscovite. Suitable for graduates and advanced undergraduates. Background necessary: physical chemistry and thermodynamics.

Reesman, A.L., E.E. Pickett, and W.D. Keller. 1969. Aluminum ions in aqueous solutions. *American Journal of Science*, 267 (1): 99-113.

The behavior of aluminum ions in solution is evaluated by the following means: electrophoresis of aluminum ions at various values of pH, re-evaluating previously determined solubility constants, and using previously published analytical data (1) to develop a consistent and workable hypothesis of the nature of the aluminum ions in aqueous solution and (2) to approximate the free energy of formation for these ions. Suitable for graduates and advanced undergraduates. Background necessary: physical chemistry and thermodynamics.

Revelle, Roger. 1955. On the history of the oceans. *Journal of Marine Research*, 14 (4): 446-461.

The author examines the questions of the volume of water on the earth's surface at different times in the past, and the former conditions in the water and in the overlying atmosphere compared with those existing today. Suitable for graduates and advanced intermediate undergraduates. Background necessary: basic chemistry and physics.

Richards, F.A. 1957. Some current aspects of chemical oceanography. *In* L.H. Ahrens, Frank Press, K.K. Rankama, and S.K. Runcorn (editors). *Physics and chemistry of the earth*, v. 2. Pergamon Press, New York: 77-128.

Though this paper is somewhat out-of-date, it still serves as a good introduction to the subject. The long reference list is almost certainly comprehensive to the date of publication. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry.

Sackett, W.M., and G.O.S. Arrhenius. 1962. Distribution of aluminum species in the hydrosphere - I. Aluminum. *Geochimica et Cosmochimica Acta*, 26 (September): 955-968.

This paper attempts to solve the apparent controversy concerning the concentration of dissolved aluminum in ocean water and also to present some information on the kinds and distribution of various species in natural waters. Suitable for graduates and intermediate and advanced undergraduates. Background necessary: basic college chemistry.

Schmalz, R.F. 1969. Deep-water evaporite deposition: A genetic model. *American Association of Petroleum Geologists Bulletin*, 53 (4): 798-823.

Inconsistencies in the theory that ancient marine evaporite deposits formed in shallow, slowly subsiding basins in regions of arid or semiarid climate are pointed out. A "deep-basin" model of evaporite deposition is shown to be geologically reasonable and oceanographically tenable, and to be consistent with the depositional histories of the Zechstein, Salina, Castile, and at least part of the Elk Point evaporites. Suitable for graduates and intermediate and advanced undergraduates. Background necessary: basic college chemistry.

Segnit, E.R., H.D. Holland, and C.J. Biscardi. 1962. The solubility of calcite in aqueous solutions-I. The solubility of calcite in water between 75° and 200° at CO_2 pressures up to 60 atm. *Geochimica et Cosmochimica Acta*, 26 (December): 1301-1331.

"The solubility of calcite in distilled water has been measured at 75°, 100°, 125°, 150° and 200°C at CO_2 pressures between 2 and 60 atm." Results are compared with previous work and fitted to curves calculated on the basis of Debye-Hückel theory. The observed decrease in calcite solubility is expected from available thermodynamic data. Simple cooling or loss of a vapor phase appear to be inadequate mechanisms to account for calcite precipitation in most ore deposits. Suitable for graduates and advanced undergraduates. Background necessary: solution chemistry and thermodynamics.

Siever, Raymond. 1957. The silica budget in the sedimentary cycle. *American Mineralogist*, 42 (11-12): 821-841.

The author discusses the sources, transportation, and precipitation of silica at or near the surface of the earth's crust in relation to the polymorphic forms of silica found in ancient and modern sediments.

The subject is treated from the standpoint of modern chemical and crystal-chemical ideas on the forms of solid and colloidal silica, the types of dissolved species in aqueous solutions, and the equilibria between solid and dissolved species at low temperatures and pressures. Suitable for graduates and intermediate and advanced undergraduates. Background necessary: basic college chemistry; some introduction to thermodynamics would be helpful for parts of the discussion. The article is presented with useful summary diagrams.

Siever, Raymond. 1968. Sedimentological consequences of a steady-state ocean-atmosphere. *Sedimentology*, 11 (1-2): 5-29.

The consequences of the surficial geochemical cycle of the earth are examined in terms of sedimentary rocks. Discussed are the kinds of sedimentological information needed and how that information should be distributed statistically in the geologic column over the sedimentary portion of the crust in order to test the geochemical hypothesis. Suitable for graduates and advanced and intermediate undergraduates. Background necessary: basic college chemistry.

Siever, Raymond, K.C. Beck, and R.A. Berner. 1965. Composition of interstitial waters of modern sediments. *Journal of Geology*, 73 (1): 39-73.

Interstitial waters were squeezed from several hundred samples of modern oceanic sediments in 22 cores from six general areas. Samples were analyzed for Ca, Mg, Na, K, Cl, and SiO_2. The general conclusions are that early diagenesis in the average marine clayey sediment is minimal, but that the composition of pore waters is a guide to incipient mineral transformations. Suitable for graduates and advanced undergraduates. Background necessary: college chemistry and basic solution chemistry.

Sippel, R.F., and E.D. Glover. 1964. The solution alteration of carbonate rocks, the effects of temperature and pressure. *Geochimica et Cosmochimica Acta*, 28 (9): 1401-1417.

The authors discuss in detail the flow transport process which is one of two processes important in the solution alteration of carbonate rocks (cf. diffusive processes), and which is associated with gradients of solubility that are uniform over distances that are very large compared with the rock grain size. "In particular, equations are developed relating the rate of change of rock density to the hydrostatic and geothermal gradients, the rock porosity, and the fluid velocity." Suitable for graduates and advanced undergraduates. Background necessary: mathematics to calculus and basic college chemistry and physics.

Sokolova, E.I. 1964. *Physicochemical investigations of sedimentary iron and manganese ores and associated rocks.* Israel Program for Scientific Translations, Jerusalem: 220 p.

The author discusses the relationship of Eh and pH to development of sedimentary ores. She details a number of empirical studies of Russian ore deposits including glauconites and phosphorites. Background necessary: basic college chemistry.

Szalay, Alexander. 1964. Cation exchange properties of humic acids and their importance in the geochemical enrichment of UO_2^{++} and other cations. *Geochimica et Cosmochimica Acta*, 28 (10): 1605-1614.

The process of the sorption of uranium from very dilute solution in natural waters by insoluble humic acids derived from plant lignin is documented. Adsorption isotherms can be adequately described by the Langmuir adsorption equation and can be characterized by two numerical constants, one representing the sorption capacity of peat, the other being the "geochemical enrichment factor." Values are determined for these. A number of other cations are similarly fixed, and those are investigated briefly. Humic acids may be useful for waste disposal problems of the atomic-energy industry. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry. The presentation includes good schematic figures.

Traganza, E.D. 1967. Dynamics of the carbon dioxide system on the Great Bahama Bank. *Bulletin of Marine Science*, 17 (2): 348-366.

Attention is directed to the problems of solubility of carbon dioxide and calcium carbonate in sea water, chemical- and physical-reaction rates, and the mechanisms of photosynthesis and precipitation of calcium salts. This paper describes a seasonal and diurnal study of the variables associated with the system on the Great Bahama Bank. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry.

Tsusue, Akio, and H.D. Holland. 1966. The coprecipitation of cations with $CaCO_3$--III. The coprecipitation of Zn^{2+} with calcite between 50 and 250°C. *Geochimica et Cosmochimica Acta*, 30 (4): 439-453.

"The distribution of Zn and Ca between solution and calcite, in NaCl-free solutions and in concentrated NaCl solutions has been measured at 50, 90, 167 and 250°C." The values of the distribution coefficient under various conditions were investigated. Geologic applications are discussed, namely the behavior of zinc in ore-forming fluids. Suitable for graduates and advanced undergraduates. Background necessary: physical chemistry and mathematics to integral calculus.

Turekian, K.K. 1968. *Oceans*. Prentice Hall, Inc., Englewood Cliffs, New Jersey: 120 p.

This book deals primarily with the geology and chemistry of oceans. Specific attention is given to the distribution of deep-sea features, the geochronometry and stratigraphy of deep-sea deposits, the chemistry of ocean water, and the history of the oceans and ocean basins. This book contains many figures; it is brief and available in paperback.

Vallentyne, J.R. 1963. Isolation of pyrite spherules from recent sediments: *Limnology and Oceanography*, 8 (1): 16-30.

The author presents a close examination of the origin of pyrite in sediments. The article includes experimental work, results of studies of numerous recent sediment samples (mostly freshwater), and a good review of the problem. The author clearly shows the organic control on the formation of pyrite spherules. The paper is well-written and well-illustrated and could easily be understood by beginning geology students. Background necessary: basic college chemistry.

Weber, J.N. 1964. Trace element composition of dolostones and dolomites and its bearing on the dolomite problem. *Geochimica et Cosmochimica Acta*, 28 (11): 1817-1868.

"Three-hundred specimens of 'primary' and 'secondary' dolostones and 150 specimens of dolomite quantitatively analyzed in triplicate for 20 trace and minor elements statistically yield separate populations of the two major lithologic varieties of dolomitic carbonate rocks for certain trace elements." Analysis of the data is directed toward establishing mechanisms of origin of "primary" and "secondary" dolomites. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry.

Weber, W.J., Jr., and Werner Stumm. 1963. Buffer systems and natural fresh waters. *Journal of Chemical and Engineering Data*, 8 (3): 464-468.

In addition to a detailed consideration of the role of the carbonate system, a comprehensive, integrated concept of the nature and interplay of the various capacity factors of other principal buffer systems indigenous to fresh waters is presented. The roles of aquatic biota, silicate minerals, and meta-ions are considered. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry.

Weyl, P.K. 1966. Environmental stability of the earth's surface--Chemical consideration. *Geochimica et Cosmochimica Acta*, 30 (7): 663-679.

To study the stability of the environment, the complexity of nature is replaced by a simplified model. At present, the dynamic equations of the environment cannot be solved. The approach proposed gives a clearer understanding of the interaction of the various parameters. It helps to point out areas in which research is required in order to quantify the coupling of the environmental variables. The resulting synthesis of the various branches of the earth and biological sciences should lead to a better understanding of the surface of the earth as a stage for life. Suitable for graduates and advanced undergraduates. Background necessary: mathematics to calculus and basic college chemistry.

APPLICATION OF CHEMICAL CONCEPTS TO NATURAL ORGANIC SYSTEMS

Abelson, P.H. 1967. Conversion of biochemicals to kerogen and *N*-paraffins. *In* P.H. Abelson (editor). *Researches in geochemistry*, v. 2. John Wiley and Sons, Inc., New York: 63-86.

This paper is of particular interest because it emphasizes genetic processes. Of special significance are heating experiments on kerogen. The nature, amount, and rate of formation of produced hydrocarbons are evaluated. The relationship of kerogen and other organic substances to the formation of petroleum is discussed. This paper would be an excellent basis for a seminar discussion. Suitable for graduate and advanced undergraduate geochemistry courses. Background necessary: basic organic chemistry, physical chemistry, geochemistry.

Ahrens, L.H. 1966. Ionization potentials and metal-amino acid complex formation in the sedimentary cycle. *Geochimica et Cosmochimica Acta*, 30 (11): 1111-1119.

The paper deals with the influence of ionization potential, ionic charge, and ionic radius of metals on the formation and stabilities of complexes with amino acids. Such complexes have a bearing on the distribution of metals in the sedimentary cycle because of the presence of metal binders, such as the amino acids, in the oceans and in some sediments. Suitable for graduates and advanced undergraduates. Background necessary: basic college inorganic and organic chemistry. Ahrens' paper is clearly written with a useful summary of previous work in this field.

Andreev, P.F., A.I. Bogomolov, A.F. Dobryanskii, and A.A. Kartsev. 1968. *Transformation of petroleum in nature*. Pergamon Press, New York: 466 p. [Translation by R.B. Gaul and B.C. Metzner; edited by E.S. Barghoorn and S.R. Silverman]

This is a major work which offers the petroleum geologist and geochemist a wealth of experimental data and a comprehensive statement of the thermodynamic principles governing petroleum transformation. Specific subjects treated include: (1) petroleum properties and geologic-geochemical conditions, (2) spontaneous alteration of organic matter, (3) thermodynamics of low-temperature transformation of hydrocarbons, (4) oxidative transformations, (5) significance of clays, (6) thermocatalytic transformations of heterogeneous organic compounds and hydrocarbons, and (7) the origin and distribution laws of petroleum hydrocarbons. The bibliography is extensive but unfortunately without article titles. The book offers an efficient means of becoming familiar with some of the best Russian work on the subject. Suitable for graduate courses and seminars. Background necessary: basic college organic chemistry and general geochemistry.

Breger, I.A. (editor). 1963. *Organic geochemistry*. The Macmillan Company, New York: 658 p.

This is a collection of 15 chapters prepared by 18 different contributors. The chapters are organized into four groups: (1) outline and principles governing the origin, diagenesis, and classification of organic biochemicals, (2) major organic deposits -- for example, humus, kerogen, coal, petroleum, and oil shales, (3) a geochemical review of important organic substances -- for example, organic pigments, amino acids, carbohydrates, and lipids, and (4) a discussion of carbonaceous substances and the geochemical cycle of various elements. The entire text is in English. Most of the papers are comprehensive and rather tedious reading. The volume will be most useful in graduate courses when used in conjunction with more current treatments. Background necessary: basic college organic chemistry; general geochemistry training and some familiarity with natural product chemistry would help.

Brooks, J.D., and J.W. Smith. 1967. The diagenesis of plant lipids during the formation of coal, petroleum and natural gas--I. Changes in the *N*-paraffin hydrocarbons. *Geochimica et Cosmochimica Acta*, 31 (12): 2389-2397.

"Eighteen coals, one crude oil, and other samples of fossil organic matter were extracted with solvents and the hydrocarbon fraction was separated in each case by chromatography and analysed by gas chromatography." It was found that diagenetic effects, at least in post-Permian times, overshadow those of age. The authors contend that in an area of subsidence, a sedimentary basin could form in which, at least in the early stages of geochemical alteration, there could be found deposits of both coal and petroleum originating from the same kind of plant life. Suitable for graduates and undergraduates. Background necessary: basic college organic chemistry.

Colombo, Umberto, and G.D. Hobson (editors). 1964. *Advances in organic geochemistry 1962*. The Macmillan Company, New York: 488 p.

The volume records the Proceedings of the First International Meeting (in Milan) of the European Branch of the Organic Geochemistry Group of the Geochemical Society. Most of the separate 40 papers are in English, but a few appear in French or German. Seven chapters are devoted primarily to analytical techniques. Organic geochemical aspects of petroleum, coal, and sedimentary rocks receive primary attention, although the book includes papers on organic matter in meteorites and in ocean and lake waters. The bibliographies are substantial but of limited value because they do not include article titles. Suitable for graduate courses. Background necessary: basic college organic chemistry.

Cooper, J.E., and E.E. Bray. 1963. A postulated role of fatty acids in petroleum formation. *Geochimica et Cosmochimica Acta*, 27 (11): 1113-1128.

"Distributions of *n*-paraffins in recent sediments differ from those in petroleum in that *n*-paraffins with odd-carbon numbers predominate in recent sediments but not in petroleum. A hypothesis proposed to explain this difference predicts a change from a preference for even-carbon-numbered fatty acids in recent sediments to no preference in petroleum waters. Studies of fatty acid distributions support this prediction

and provide evidence for a relationship between fatty acid and *n*-paraffin distributions." Suitable for graduates and advanced undergraduates. Background necessary: basic college organic chemistry.

Degens, E.T., J.H. Reuter, and K.N.F. Shaw. 1964. Biochemical compounds in offshore California sediments and sea waters. *Geochimica et Cosmochimica Acta*, 28 (1): 45-66.

"Amino acids and sugars in marine basin sediments, in particulate matter of overlying waters, and in solution in these waters were investigated." Biogeochemical differences between the sediments and overlying waters were analyzed. "A tentative interpretation is offered as to the probable source of the organic matter in the sediments." Suitable for graduates and advanced undergraduates. Background necessary: basic college organic chemistry.

Dubach, P., N.C. Mehta, T. Jakab, F. Martin, and N. Roulet. 1964. Chemical investigations on soil humic substances. *Geochimica et Cosmochimica Acta*, 28 (10): 1567-1578.

"Results of extensive studies on the basic problems of extraction, isolation, fractionation, and purification of soil humic substances are presented. Data on the degradation, functional group analysis and molecular weight determination of purified humic fractions from the β-horizon of a podzol are reported, and the role of humic substances in the podzolization process is discussed." Suitable for graduates and advanced undergraduates. Background necessary: basic college organic chemistry.

Eglinton, Geoffrey, and M.T.J. Murphy (editors). 1969. *Organic geochemistry, methods and results.* Springer-Verlag, New York: 828 p.

This book is an unusually comprehensive and up-to-date treatment of the most important aspects and research activities in this field. Each of the 31 chapters written by some 37 contributors is a significant technical paper. The chapters divide roughly into groups emphasizing (1) analytical methods, (2) general geologic processes and principles, (3) geologic abundance of specific classes of organic compounds, and (4) specific geologic situations. Bibliographies are extensive. A few of the specific subjects treated include: mass spectrometry in organic geochemistry; gas chromatography; paleobiochemistry; fossilization processes; biogeochemistry of stable carbon isotopes; hydrocarbons; fatty acids, alcohols, carbohydrates, terpenoids, carotenoids, proteins, and porphyrins; kerogen; petroleum; and coals. Suitable for graduate courses. Background necessary: basic college organic chemistry for most of the book, but the chemically oriented geologist can gain from many of the chapters.

Eichholz, G.G., T.F. Craft, and A.N. Galli. 1967. Trace element fractionation by suspended matter in water. *Geochimica et Cosmochimica Acta*, 31 (5): 737-745.

"Fractionation of trace elements by silt and sediment particles in natural waters" was studied by means of radioactive tracers. Although the work was concentrated on a series of fission products, these elements were probably sufficiently varied in their chemical characteristics to serve as valid indicators of the order of magnitude of fractionation to be expected between elements of various groups in the periodic table. Suitable for graduates and advanced undergraduates. Background necessary: introductory clay mineralogy and basic college chemistry.

Gordon, J.E., and R.L. Thorne. 1967. Salt effects on non-electrolyte activity coefficients in mixed aqueous electrolyte solutions--II. Artificial and natural sea waters. *Geochimica et Cosmochimica Acta*, 31 (12): 2433-2443.

The authors state that an understanding of the salting-out effects of major sea-salt components is essential (1) to the study of nonelectrolyte solubilization (solubility enhancement in the presence of micelle-forming organic surfactants), (2) to the quantitative treatment of chemical rate and equilibrium processes in sea water, and (3) perhaps to understanding the deposition of organic matter in the salinity-gradient zones of estuaries. A fundamental study of the salting-out of naphthalene by a variety of two-salt mixtures was reported in Part I of this series. Using naphthalene again, an extension is made of the observations to a "ten-salt mixture (artificial sea water), then to a comparison with natural sea water and finally to solutions containing added solubilizers." Suitable for graduates and advanced undergraduates. Background necessary: calculus and basic college physical and organic chemistry.

Hayatsu, Ryoichi, M.H. Studier, Atsuko Oda, Kiyono Fuse, and Edward Anders. 1968. Origin of organic matter in early solar system--II. Nitrogen compounds. *Geochimica et Cosmochimica Acta*, 32 (2): 175-190.

The first paper in this series showed that all hydrocarbons reliably identified in meteorites can be made from CO and H_2 in the presence of an iron-meteorite catalyst. This paper shows experimentally that spontaneous reactions involving no external energy source can also account for other types of organic

compounds found in meteorites. A meteorite was re-examined to confirm and extend previous identifications of nitrogen compounds. Two compounds, being constituent bases of DNA and RNA, are of extraordinary interest. Suitable for graduates and advanced undergraduates. Background necessary: college organic chemistry.

Hobson, G.D., and M.C. Louis (editors). 1966. *Advances in organic geochemistry 1964.* Pergamon Press, New York: 330 p. [Proceedings of the International Meeting in Rueil-Malmaison 1964]

This collection of 23 papers (chapters) by various research workers reflects a diversity of interests and topics of organic geochemistry. Problems concerning organic substances in sedimentary rocks (for example, isoprenoid alkanes in a Precambrian sediment) receive considerable emphasis, although organic geochemical data on petroleum and topics related to the origin of oil are also covered. Eleven chapters are in French and two are in German; there are no English summaries. Most papers are for the specialist. Suitable for graduate courses. Background necessary: French and German, basic college organic chemistry, general knowledge in geochemistry.

Johns, R.B., Theodore Belsky, E.D. McCarthy, A.L. Burlingame, Pat Haug, H.K. Schnoes, W. Richter, and Melvin Calvin. 1966. The organic geochemistry of ancient sediments - Part II. *Geochimica et Cosmochimica Acta,* 30 (12): 1191-1222.

"Biological markers" from several shales and oils are used to suggest the presence of life processes as early as 2.7 billion years ago. It is argued that the high level of development of the biological processes implied by the results in this and other papers calls for inception of bio-organic evolution at a substantially earlier period. "Biological markers" are defined as compounds that show reasonable chemical stability to diagenesis and possess a marked specificity of structure understandable in terms of known biosynthetic sequences, and whose formation by abiological synthesis is of low probability. Suitable for graduates and advanced undergraduates. Background necessary: college organic chemistry with some instruction in interpretation of gas chromatography and mass spectrometry. The paper is written for an audience with some knowledge of the field.

Mair, B.J. 1964. Terpenoids, fatty acids and alcohols as source materials for petroleum hydrocarbons. *Geochimica et Cosmochimica Acta,* 28 (8): 1303-1321.

An argument is made for the terpenoids, abundant among land and marine plants and animals, as the source for hydrocarbons with aromatic or cyclohexane rings and for the cyclopentanes; the acyclic terpenoids as progenitors of the slightly branched alkane hydrocarbons; and straight-chain fatty acids and alcohols as progenitors of the normal paraffins. Suitable for graduates and advanced undergraduates. Background necessary: basic college organic chemistry. The paper is presented with good molecular-structure diagrams.

Manskaya, S.M., and T.V. Drozdova. 1968. *Geochemistry of organic substances.* Pergamon Press, New York: 345 p. [Translated and edited by Leonard Shapiro and I.A. Breger]

This rather specialized work is divided into two major parts: (1) mineralized organic substances and their formation, and (2) concentration of metals by organic substances in sedimentary rocks. The nature and occurrence of diversified organic substances (proteins, carbohydrates, phenols, humic acids, and others) in peat, coal, and contemporary and ancient sediments are emphasized in the first part. The interplay of organic matter and uranium, germanium, vanadium, molybdenum, and copper is emphasized in the second part. Other metals are also treated. The second part will be of special interest to the trace-element sedimentary geochemist. Suitable for graduate courses. Background necessary: basic organic chemistry and geochemical knowledge.

Minton, A., and E. Rosenberg. 1964. The effect of temperature on the preservation of purine and pyrimidine bases. *Geochimica et Cosmochimica Acta,* 28 (12): 1953-1959.

"The aerobic solid phase decomposition of the five major naturally-occurring purine and pyrimidine bases of the nucleic acids was studied spectrophotometrically." Suitable for graduates and advanced undergraduates. Background necessary: organic chemistry and kinetics.

Philippi, G.T. 1965. On the depth, time and mechanism of petroleum generation. *Geochimica et Cosmochimica Acta,* 29 (9): 1021-1049.

Conclusions are drawn about the depth, time, and mechanism of petroleum generation from a detailed study in the Los Angeles and Ventura basins, California. Suitable for graduates and intermediate and advanced undergraduates. Background necessary: basic college organic chemistry. The paper contains good subheadings, graphs, and tables.

Schalscha, E.B., Herbert Appelt, and Albert Schatz. 1967. Chelation as a weathering mechanism--I. Effect of complexing agents on the solubilization of iron from minerals and granodiorite. *Geochimica et Cosmochimica Acta*, 31 (4): 587-596.

"This work is a continuation of previous studies on the role of chelation as a weathering mechanism." It was demonstrated that salicylate "and several naturally-occurring chelating agents, in the form of free acids or their alkali salts, extracted Fe from goethite, hematite, magnetite, epidote, augite, biotite, and granodiorite. K and Al were brought into solution when salicylate reacted with epidote, microcline and granodiorite. Salicylate and 8-hydroxy-quinoline extracted Fe from epidote in non-aqueous media. There was no direct correlation between pH and the dissolving action of various reagents. For this and other reasons, the results are interpreted as additional evidence implicating chelation as a weathering process." Suitable for graduates and advanced undergraduates. Background necessary: college organic chemistry.

Studier, M.H., Ryoichi Hayatsu, and Edward Anders. 1968. Origin of organic matter in early solar system -- I. Hydrocarbons. *Geochimica et Cosmochimica Acta*, 32 (2): 151-173.

A hypothesis to explain the origin of meteoric hydrocarbon is proposed. The hypothesis is that the hydrocarbons formed metastably in the solar nebula by spontaneous reactions of CO, H_2, and NH_3 involving no external energy source, and were later modified by partial equilibration. Attempts were made to synthesize hydrocarbons by spontaneous reactions, using starting materials likely to have been present in the solar nebula. Concurrently, meteoric hydrocarbons were re-examined using gas chromatography/mass spectrometry. Suitable for advanced undergraduates or graduates. Background necessary: college organic chemistry.

Vallentyne, J.R. 1964. Biogeochemistry of organic matter--II. Thermal reaction kinetics and transformation products of amino compounds. *Geochimica et Cosmochimica Acta*, 28 (2): 157-188.

"In this second contribution to the series, a study has been made of the ninhydrin-reactive products produced on the pyrolysis of amino acid solutions, and detailed data have been obtained on the kinetics of thermal decomposition of four amino acids." The overall aim of the investigations reported in this series is to construct a theoretical framework for biological compounds that may aid in interpreting analytic data on fossil materials. Suitable for graduates and advanced undergraduates. Background necessary: college organic chemistry and kinetics.

Watts, H. 1963. The possible role of adsorption and diffusion in the accumulation of crude petroleum deposits; a hypothesis. *Geochimica et Cosmochimica Acta*, 27 (8): 925-928.

"It is proposed that a temperature gradient in sediments is a driving force for migration of petroleum into reservoir rocks. This temperature gradient could be effective due to its influence on both the adsorption and diffusion processes involved in petroleum migration." Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry.

APPLICATION OF CHEMICAL CONCEPTS TO ISOTOPE GEOLOGY

Bigeleisen, Jacob. 1965. Chemistry of isotopes: *Science*, 147 (3656): 463-471.

The author presents a short review of the chemistry of isotopes and how isotope chemistry may be used in solving geologic problems. Emphasis is on stable isotopes from the standpoint of both inorganic and biologic fractionation. The article is valuable for the geologist with a good chemistry background who is interested in learning why isotopes are a valuable geochemical tool.

Cheney, E.S., and M.L. Jensen. 1965. Stable carbon isotopic composition of biogenic carbonates. *Geochimica et Cosmochimica Acta*, 29 (12): 1331-1346.

Field and laboratory data are used to show that anaerobes produce isotopically heavier CO_2 and lighter methane than the associated organic material which they consume as an energy source. The hypothesis is advanced that a spectrum of values could be obtained by the oxidation of methane and contamination by the original bacterial CO_2 and sedimentary carbonate. The stable carbon isotope composition is obtained in limestones from three deposits where there is evidence of anaerobic bacterial activity. The quantized values of the three deposits are explained as evidence of strong geologic control. Suitable for graduate and advanced undergraduate courses. Background necessary: basic college chemistry and some introduction to stable isotopes. The reader should consult a later amendment to this paper.

Clayton, R.N., B.F. Jones, and R.A. Berner. 1968. Isotope studies of dolomite formation under sedimentary conditions. *Geochimica et Cosmochimica Acta*, 32 (4): 415-432.

Measurements of oxygen and carbon isotope abundances indicate the presence of at least three phases (magnesian calcite, primary sedimentary dolomite, and detrital dolomite) in the carbonate portion of a lake sediment. The isotopic compositions of the first two are consistent with precipitation at isotopic equilibrium from waters of the lake area and indicate that the dolomite has formed by direct crystallization from solution and not from a calcite precusor without further isotopic exchange. Background necessary: basic college chemistry and some introduction to stable isotopes. The article is clearly and logically presented and contains good diagrams.

Degens, E.T., and Samuel Epstein. 1964. Oxygen and carbon isotope ratios in coexisting calcites and dolomites from recent and ancient sediments. *Geochimica et Cosmochimica Acta*, 28 (1): 23-44.

"The O^{18}/O^{16} and C^{13}/C^{12} ratios of coexisting sedimentary dolomites and calcium carbonates from a variety of environments, modes of formation and geological age were measured. The data reflect the processes of dolomitization of calcium carbonates and their subsequent history." Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry and some introduction to stable isotopes.

Emiliani, Cesare. 1966. Isotopic paleotemperatures. *Science*, 154 (3751): 851-857.

This article is a good review of the use of oxygen isotopes in determining temperatures in carbonate rocks and sediments. Emphasis is on the Pleistocene, but applications to older rocks are also discussed. The paper requires only a basic knowledge of chemistry and should be easily understood by beginning students. The interested reader may wish to refer to Emiliani's more detailed 1955 paper which is referenced in this article.

Epstein, Samuel, and Toshiko Mayeda. 1953. Variation of O^{18} content of waters from natural sources. *Geochimica et Cosmochimica Acta*, 4 (5): 213-224.

The authors present a report of the O^{18} content of a wide variety of natural waters, showing the relationship of oxygen isotopes to salinity through the process of distillation. Accent is placed on environmental control of isotope fractionation. This paper could easily be understood by students in introductory geology; only a basic knowledge of chemistry is required.

Faul, Henry. 1966. *Ages of rocks, planets, and stars*. McGraw-Hill Book Company, New York: 109 p.

This paperback is a short (100 page) survey covering a broad range and touching on both the highlights and sidelights of radiometric dating. It is well-written and diagrammed in a simple, easily understood style. It covers the basic principles of radioactivity and a variety of specific geologic-dating methods. The limitations and special problems are discussed. There is an excellent discussion of concordant and discordant dates. The development of the geologic time scale is sufficiently covered and the problems and techniques of cosmic dating are well-developed. This book is excellent supplementary reading for a geochemistry course and would make an inexpensive second text for a course on isotope geology. Background necessary: physical geology, basic chemistry, physics, and mathematics.

Faure, Gunter, and P.M. Hurley. 1963. The isotopic composition of strontium in oceanic and continental basalts: Application to the origin of igneous rocks. *Journal of Petrology*, 4 (1): 31-50.

The isotopic compositions of strontium of oceanic and continental basalts were found to be constant within narrow limits. The average Sr^{87}/Sr^{86} ratio of 11 oceanic basalts was 0.7072 ± 0.003; 14 continental basalts had an average value of 0.7082 ± 0.0003. The apparent isotopic homogeneity of strontium in basaltic rocks derived from source regions in the upper mantle was contrasted with the isotopic heterogeneity of strontium in the continental crust. As a result of rubidium enrichment (Rb/Sr = 0.25) and average age ($t \sim 2 \times 10^9$ yr), the average Sr^{87}/Sr^{86} ratio of the continental crust was estimated to be 0.725. It is suggested that the initial Sr^{87}/Sr^{86} ratios of granitic rocks can be used to distinguish mantle-derived rocks from those which have formed by recrystallization or remelting of pre-existing crustal rocks. This criterion was used to show that the alkalic igneous rocks of the Monteregian Hills, Quebec, Canada, originated in the upper mantle and were not contaminated by assimilation of granitic rocks of Precambrian age into which they were intruded. This article is intended for petrologists and isotope geologists interested in the Rb^{87}-Sr^{87} decay scheme.

Faure, Gunter, P.M. Hurley, and J.L. Powell. 1965. The isotopic composition of strontium in surface water from the North Atlantic Ocean. *Geochimica et Cosmochimica Acta*, 29 (4): 209-220.

The isotope composition of strontium in ten samples of surface water from the North Atlantic Ocean was found to be constant. The average Sr^{87}/Sr^{86} ratio is 0.7093 ± 0.0005, corrected for isotope fractionation relative to Sr^{86}/Sr^{88} = 0.1194. All previously published analyses of the isotope composition of strontium in sea water are tabulated, and the conclusion is that the Sr^{87}/Sr^{86} ratio of the modern oceans is constant. The isotope composition of strontium in the oceans is explained in terms of mixing of strontium derived from three sources: (1) old igneous and metamorphic rocks and sedimentary rocks derived from them (Sr^{87}/Sr^{86} = 0.715), (2) young volcanic rocks (Sr^{87}/Sr^{86} = 0.704), and (3) marine carbonate and sulfate rocks (Sr^{87}/Sr^{86} = 0.708). The paper is intended for geochemists interested in the oceans and for isotope geologists interested in the Rb^{87}-Sr^{87} decay scheme.

Garlick, G.D., and Samuel Epstein. 1967. Oxygen isotope ratios in coexisting minerals of regionally metamorphosed rocks. *Geochimica et Cosmochimica Acta*, 31 (2): 181-214.

The minerals analyzed are magnetite, ilmenite, chlorite, biotite, garnet, kyanite, muscovite, feldspar, and quartz. Regularities in fractionation suggest crystallization in isotopic equilibrium. Previous experimentally determined quartz-magnetite fractionations are used to get estimates of temperature during metamorphism. Local homogeneity in isotopic composition of particular minerals among dissimilar rocks is attributed to isotopic exchange with mobile pore fluids during metamorphism. Suitable for graduate students and advanced undergraduates. Background necessary: basic college chemistry and some introduction to stable isotopes. This is a long paper in which the general discussion of results and the summary and conclusions are very informative and clearly written.

Goldberg, E.D., and Minoru Koide. 1962. Geochronological studies of deep sea sediments by the ionium/thorium method. *Geochimica et Cosmochimica Acta*, 26 (March): 417-450.

"The ionium/thorium method for determining the rates of accumulation of marine sediments has been applied to a group of deposits from the Pacific, Atlantic and Indian Oceans...A model for the mixing of the upper layers of the sediment, by worm burrowing or near-bottom currents, is proposed, and if valid, allows the depth of mixing to be ascertained from the ionium/thorium profiles." Surface values of the ionium/thorium ratio showed a marked geographic dependence which was attributed to the relative amounts of continental runoff an ocean area receives. Suitable for graduates and advanced undergraduates. Background necessary: radioactive decay chemistry.

Hamilton, E.I. 1965. *Applied geochronology*. Academic Press, London: 267 p.

An explanation is given of the measurement of geologic time based on the radioactive decay of the following isotopes occurring in geologic materials: C^{14}, K^{40}, Rb^{87}, Re^{187}, U^{238}, U^{235}, and Th^{232}. The physical principles and assumptions of dating are explained. The book contains useful information regarding analytical procedures and instrumentation and includes a brief review of the comparative geochemistry of K, Rb, Ca, Sr, Ar, U, Th, and Pb, written by L.H. Ahrens. There is a short introductory chapter on the history of isotope geology. Several other dating techniques are treated cursorily: fission-track dating, pleochroic haloes, radiation damage, lead-alpha method, He dating, and several methods of dating deep-sea sediment based on the disequilibrium decay of radioactive daughters of U and Th. The book would be useful as a textbook for graduate or undergraduate students majoring in geology.

Hamilton, E.I., and R.M. Farquhar (editors). 1968. *Radiometric dating for geologists*. Interscience Publishers [John Wiley and Sons], New York: 506 p.

This book presumes an elementary understanding of radiometric age dating and proceeds to treat different topics in some depth. These topics include K-Ar, U-Pb, Rb-Sr, common lead, common strontium, and fission-track studies of various complex crustal regions or rock types. Geologists and geochemists who wish to have more than a cursory insight into applications of isotope geology will find that the treatment is satisfying and that new situations can be evaluated with some degree of sophistication. This text is recommended as a background for a course in isotope geology or geochronology.

Hurley, P.M., B.C. Heezen, W.H. Pinson, and H.W. Fairbairn. 1963. K-Ar age values in pelagic sediments of the North Atlantic. *Geochimica et Cosmochimica Acta*, 27 (4): 393-399.

The conclusions from the study are: K-bearing mineral components in North Atlantic pelagic sediments are dominantly allogenic, with K-Ar age values in the range 200-400 million years; observed regional age differences suggest that K-Ar ages may be useful in mapping average long-term atmospheric or oceanic circulations; and age differences with depth in the sediment, believed to represent paleowind and paleo-current circulations, suggest that this type of analysis may have use in stratigraphic correlation and paleoclimatology. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry and some introduction to K-Ar dating.

Kemp, A.L.W., and H.G. Thode. 1968. The mechanism of the bacterial reduction of sulphate and of sulphite from isotope fractionation studies. *Geochimica et Cosmochimica Acta*, 32 (1): 71-91.

The fractionation of sulfur isotopes in the reduction of sulfate and sulfite by the bacteria *Desulphovibrio desulphuricans* was studied experimentally under a wide range of laboratory conditions. The results are discussed in terms of a reaction mechanism involving several consecutive steps, favoring a small or large isotope effect, competing for control of the rate. Sulfur isotope distribution patterns reported for various types of marine environments and sediments are discussed in terms of isotope effects. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry and some introduction to stable isotopes.

Lloyd, R.M. 1966. Oxygen isotope enrichment of sea water by evaporation. *Geochimica et Cosmochimica Acta*, 30 (8): 801-814.

An evaporation mechanism proposed by Sverdrup as a model to interpret the changes in isotopic composition that occur during the evaporation of sea water was investigated. Three experiments were run and oxygen isotopic enrichment of some hypersaline waters are interpreted in the light of the experimental findings. "The relative humidity at the site of evaporation is shown to be an important factor in determining the net isotopic enrichment, especially at very high salinities." Suitable for graduates and advanced undergraduates. Background necessary: inorganic college chemistry and some introduction to stable isotopes. The text contains some good schematic diagrams.

Lowenstam, H.A., and Samuel Epstein. 1957. On the origin of sedimentary aragonite needles of the Great Bahama Bank: *Journal of Geology*, 65 (4): 364-375.

Stable isotopes of carbon and oxygen suggest that much of the carbonate sediment in the Bahamas is of biogenic (algal) origin. The authors provide a good review of the origin of calcium carbonate muds and a good review of the application of carbon and oxygen isotope studies to low-temperature geologic systems. The article is well-written at a level which could be easily understood by a beginning geology student with only a basic chemistry background.

Naki, Nobuyuki, and M.L. Jensen. 1964. The kinetic isotope effect in the bacterial reduction and oxidation of sulfur. *Geochimica et Cosmochimica Acta*, 28 (12): 1893-1912.

"The kinetic isotope effect in the bacterial reduction of sulfate to sulfide and oxidation of native sulfur and sulfide to sulfate has been investigated at the temperature of 32°C. In these studies, mixed culture techniques were used in order to more closely approximate isotopic fractionation as it occurs in nature. In addition, the $\delta\ S^{34}$ compositions of sulfur in coexisting sulfate and sulfide in lake waters and streams were determined for comparison to the laboratory raw culture results." Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry and some introduction to stable isotopes.

Parker, P.L. 1964. The biogeochemistry of the stable isotopes of carbon in a marine bay. *Geochimica et Cosmochimica Acta*, 28 (7): 1155-1164.

"The most abundant biological samples from Redfish Bay, a shallow marine estuary near Port Aransas, Texas, were collected, and $\delta\ C^{13}$ for the total carbon, lipid carbon and protein-carbohydrate carbon was measured." It was concluded that the organic matter of the sediment could have been supplied by the community according to the carbon isotope data. A 5/mil diurnal variation in $\delta\ C^{13}$ of the inorganic carbon of the sea water of a simple marine community corresponding to the diurnal respiration cycle, was observed. The "mean fractionation factor" of carbon isotopes for biologic processes does not appear to be useful because of the wide variety of carbon isotope compositions found between different members of the community. Considering the complex distribution of $\delta\ C^{13}$ in this community and the previously reported narrow range for sedimentary carbon and petroleum, it is proposed that there may be some process operating in the sediments to homogenize the carbon with respect to $\delta\ C^{13}$. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry and biology and some introduction to stable isotopes.

Sharma, Taleshwar, and R.N. Clayton. 1965. Measurement of O^{18}/O^{16} ratios of total oxygen of carbonates. *Geochimica et Cosmochimica Acta*, 29 (12): 1347-1353.

The commonly used phosphoric acid procedure for the determination of oxygen isotope abundances in carbonates involves a large kinetic isotope effect. The value of the fractionation factor α has been measured for several alkaline-earth and transition-metal carbonates. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry and some introduction to stable isotopes.

Taylor, H.P., Jr., M.B. Duke, L.T. Silver, and Samuel Epstein. 1965. Oxygen isotope studies of minerals in stony meteorites. *Geochimica et Cosmochimica Acta*, 29 (5): 489-512.

A comparison is made of the oxygen isotope constitution of minerals in meteorites with similar minerals in analogous terrestrial rocks. The data suggest the separation of stony meteorites into three groups which may be genetically distinct. Sixteen points are listed in the "Summary and Conclusions" of the paper. Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry, petrology, some introduction to stable isotopes.

Thode, H.G., Jan Monster, and H.B. Dunford. 1961. Sulphur isotope geochemistry. *Geochimica et Cosmochimica Acta*, 25 (3): 159-174.

Sulfur isotope abundances of 39 specimens of 17 meteorites are reported. The S^{32}/S^{34} ratio for meteorites is discussed as a possible base level from which fractionation of the earth's crust began. The S^{32}/S^{34} ratios of a large suite of sea-water samples collected from widely separated points in three oceans at various depths were investigated. "Sulphur isotope ratios of sulphur in a sea shell, sulphides in shallow ocean sediments, sulphate in rain water and in present-day formation of gypsum evaporites from the sea, have been measured and are compared with the sea water level. The geochemical sulphate cycle is discussed in the light of these results." Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry and some introduction to stable isotopes.

Weber, J.N. 1964. Carbon isotope ratios in dolostones: Some implications concerning the genesis of secondary and "primary" dolostones. *Geochimica et Cosmochimica Acta*, 28 (8): 1257-1265.

"C^{12}/C^{13} ratios, in conjunction with aluminum and chloride ion contents of some Paleozoic dolostones, suggest that some of the fine grained, so-called 'primary' dolostones may have originated in areas receiving appreciable terrestrial detrital material, whereas other fine grained dolostones originated in evaporitic basins. Coarse grained, so-called 'secondary' dolostones appear to have formed in normal marine environments where conditions of normal salinity and low clay mineral content permitted the formation of bioclastic limestones." Suitable for graduates and advanced undergraduates. Background necessary: basic college chemistry with some introduction to stable isotopes.

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